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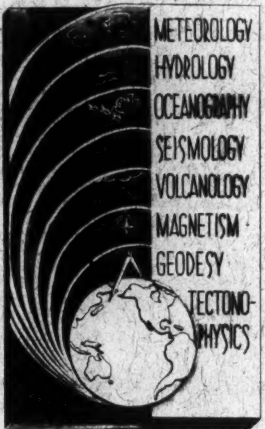
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TRANSACTIONS
AMERICAN GEOPHYSICAL UNION

Volume 26 AUGUST, 1945 Part I

SEVENTH AWARD OF THE WILLIAM BOWIE MEDAL

CITATION

F. W. Reichelderfer

Mr. President: The Committee on Award of the WILLIAM BOWIE MEDAL has selected a meteorologist for the 1945 award, and I have been asked to present to you the name of Dr. JAKOB BJERKNES, Head of the Department of Meteorology, University of California in Los Angeles, as the seventh recipient and the first meteorologist to be awarded the WILLIAM BOWIE MEDAL. He has been duly elected by the Committee in accordance with the terms of the award. The exigencies of war prevent him from being present at this meeting of the American Geophysical Union.

The name BJERKNES is well known in science through the work of three generations of this family--the current selectee, his father, and grandfather. In meteorology, J. BJERKNES is recognized far and wide for his early research and writings leading to the development of the meteorological techniques known as frontal analysis. There comes to few men the fortunate combination of achievement and timeliness that characterized his original concepts on the structure of moving cyclones and the meteorological conditions for the formation of rain and gave to these concepts the wide recognition and acceptance they deserved. The wartime events and national needs which attended his early studies contain something of the dramatic that adds interest to the story of the evolution of his methods--details that cannot be included in this brief account. Regardless of whatever modifications may come later from more complete knowledge of the atmosphere, the principles and the models of extra-tropical cyclones developed by BJERKNES and his colleagues, have had and will continue to have a profound influence on modern progress in synoptic meteorology. His techniques have become the guide for daily weather-map analysis by meteorologists everywhere and his talent for organizing and systematizing the multitudinous details and variations of the so-called meteorological elements have given new significance to and understanding of the endless parade of the weather.

Doctor Jakob Aall Bonnevie Bjerknes
Recipient seventh award of William Bowie Medal,
June 1, 1945

BJERKNES' early studies were carried on in an atmosphere that harmonized with their relationship to the geophysical sciences. His work centered around the Geophysical Institute, Bergen, Norway, where at different times he served as Superintendent of the Weather Forecast District of Western Norway, and Research Professor of the Institute. His years in Bergen were occasionally interspersed with periods of study in meteorological institutes on the Continent, in England, and in the United States, and he has served several times with international groups in meteorology and geophysics, among these the Committees of the International Meteorological Organization and the Association of Meteorology of the International Union of Geodesy and Geophysics. He has been Secretary of this Association for several years. His numerous lectures and scientific papers, some in French or German and many in English, deal with various aspects of theoretical and applied meteorology. In 1940 he was awarded the Symons Medal in London. Above all his work in theoretical subjects has exemplified the importance of tying together the complex facts of meteorology into a coordinated, three-dimensional analysis with constant reference to weather-observations and the autographic meteorological records which constitute the experimental facts of meteorology and hold the confirmation or invalidation of every meteorological theory. Some of his work has been carried over and applied to the problems of oceanography and other fields of science, and thus he is indeed one whose "distinguished service in geophysics and outstanding contribution to the advancement of cooperative research in this field of science" qualify him for the WILLIAM BOWIE MEDAL.

In addition to his scientific attainments, the candidate is endowed with charming traits of personality, and these remarks would not be complete without reference to his modest nature and the never-failing objectivity of his viewpoint. Knowing these qualities from many years of association, I take great personal pleasure in presenting the name of Dr. JAKOB AALL BONNEVIE BJERKNES for the seventh award in absentia, June 1, 1945, of the WILLIAM BOWIE MEDAL.

REPLY AND ACCEPTANCE BY DOCTOR BJERKNES

I am deeply grateful to my fellow geophysicists for the award of the WILLIAM BOWIE MEDAL. I consider it a great honor to receive a citation from a research organization of such a distinguished record as that of the American Geophysical Union. That record, although not very long compared with those of venerable societies of the fundamental sciences, has represented items of important progress in the endeavor of making science serve modern mankind. It is gratifying that the organized development of the geophysical sciences occurred just during a period when scientific preparedness became essential for the building of a strong defense and later also for the forging and optimum use of deadly weapons of offense.

Looking ahead, I think, we can see a great future for our research organization. The handful of men who carried on geophysical research in the past will be joined by a much greater number of potential research workers who came to our field through the war-training courses. Never before has so much young talent been ready to step in and tackle the many geophysical problems still left to be solved.

Transactions, American Geophysical Union Volume 26, Part I August, 1945

NATIONAL AND REGIONAL WORK-POTENTIALS, 1790-1958

W. T. Thom, Jr.*

We are living in the midst of a world-crisis, which has grown progressively more acute throughout the past half-century. This situation stems from a lack of proper functional development and articulation of the world's overall economic, political, and strategic organizations, and it is through critical, cooperative, and quantitative study of these conditions that we may reasonably hope to sort out the facts from the fallacies, and so coordinate and organize our information as to lead us both to correct appraisals of the relative capacities and resources of the various national populations--and to such international arrangements as will be mutually beneficial and satisfying.

As prerequisites for the development of sound solutions for the present problems of our dynamic world, it is clear that we must have (a) adequate quantitative data descriptive of present controlling circumstances, (b) sound historical perspectives on the forces and psychologies which have built the present crises, and (c) adequate qualitative and quantitative evaluations of the regional and world trends in social, industrial, and strategic affairs, which must be properly allowed for if our hopes for a just and durable peace are to be realized.

Three principal factors are present in any equation which gives a quantitative statement of the total world-problem. One such factor is derivable from a study of relative population-sizes and of the trends in growth of population. A second and closely related composite factor stems from the present world-circumstances of power-production and of power-distribution, and from the very unequal and irregular distribution of the world's natural power-resources over the Earth's surface. And the third (composite) factor gives an evaluation of regional capacities for developing, arranging, and applying technologic skills and facilities--as now limited and qualified by the social, religious, and political desires of different population-groups and nations. Of these three factors the second is the decisive one at the present time--for at the present moment the economic, political, and social activities of all countries are, after all (to paraphrase DeGolyer) but "dependent functions of a single set of independent variables--the rates of power-production (or work-potential) in different parts of the world". Such "work-potentials" are, the writer believes, susceptible to at least a rough quantitative estimation and evaluation, according to a method which is illustrated by the diagrams to follow (see Figs. 1-5). The writer also believes that by suitable critical and cooperative studies along this line it will be possible to compute with reasonable accuracy the rates at which these national and regional work-potentials are being, or can be, effectively converted into accomplished work or "national power".

By means of cooperative quantitative factual studies of this sort it seems certain that we should be able to sort out the facts from the fallacies among our current opinions, and we should also be able to state our world-problems in such precise and graphic form as to point the way to functionally sound and mutually and popularly satisfactory conclusions.

The principal sources of "work-potential"

The chief sources of work-potential at this time are: Human labor; the work-capacity of domesticated animals; and the energies of wood and peat (and similar fuels); coal (both of the coking and non-coking ranks); petroleum and natural gas; and water-power.

In addition to these principal present sources of energy there are others which are even now of considerable local importance (as for example wind-power and volcanic steam). And there are other sources of energy which may be made important by further physical-technological research.

National inequalities in present work-potential development

However, at the present moment (as shown by Fig. 4), the more primitive (and less powerful) civilizations derive their productive capacities from the employment of human and animal labor, from the energies of vegetable fuels, and from a limited use of small water-powers. Other countries, which have advanced to a semi-modern stage of industrialization not only draw upon the energy-sources just mentioned but also produce and consume large quantities of coal. And the modern "Great Powers" (see Fig. 1) have not only added petroleum to their important energy-sources, but have also concentrated upon the development and employment of mass-production techniques, and upon the production and use of the many alloy-metals and other strategic "energy-savers" which are so important in improving the efficiencies with which current "work-potentials" are being transformed into "work accomplished".

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* Member, American Geophysical Union's Special Committee on National Welfare and Related Functions and Chairman, American Geophysical Union's Special Committee on Geophysical and Geological Study of Continents.

No nation which lacks a large domestic production of coal and petroleum can have, as of the present moment, more than a very limited economic, political, or military power, and every nation's ability to maintain its cultural and (local) political autonomy will inevitably depend either upon its speedy development of domestic sources of all of the energies and raw materials essential to present economic and military security, or upon its voluntary participation in an economic federation covering a region at least sufficiently large to include available supplies of all of the raw materials and energies vital to both economic and military safety. Ideally this "region of free and safe interchange of goods and services" includes the whole world, but this ideal economic condition will necessarily have to be approached in two steps, in order to provide circumstances under which the peoples with high standards of living can maintain and improve their standards, even while they are assisting with the attainment of similar economic levels by the less industrialized peoples, who now seek their economic and political freedom.

Furthermore, since the advance of modern physical-chemical and engineering technology makes it more and more possible to accomplish industrial transformations and transmutations to almost any degree desired--if only enough cheap energy is available--it is possible to obtain a fairly accurate statement of our present international problem through the compilation and analysis of the many statistical reports now available, which describe the size of human populations, the annual rates of fuel and electric-power production in different areas, and the known geologic conditions and energy-reserve situations in the various world-regions.

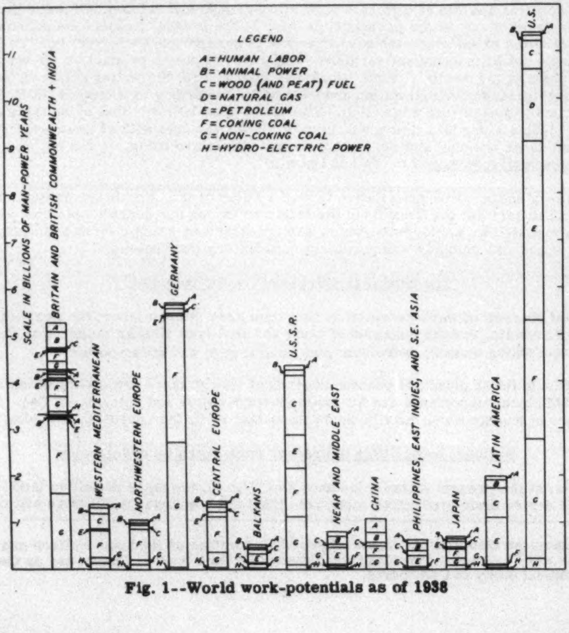


Fig. 1--World work-potentials as of 1938

Graphs showing relative work-potentials, by areas

In the first of the graphs (Figs. 1 to 5), the writer has included "natural energy" or "work-potential" figures for the year 1938--this being the last year for which world-figures on outputs of fuel were essentially complete. Within these graphs are included the work-potentials based upon current main sources of energy, as follows: Human populations; farm-animal populations; and the actual or estimated 1938 national annual outputs of coal, petroleum, natural gas, wood and peat fuel; and hydro-electric power. These animal- and fuel-energy figures have been calculated first to "horse-power years" of "work-potential", then to "man-power years", and lastly the resultant figures have been totalled by countries or groups of countries.

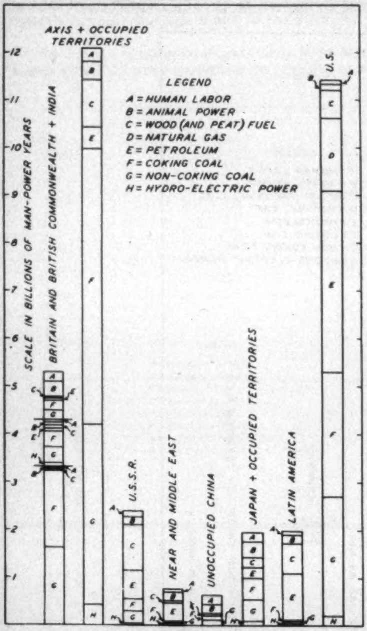


Fig. 2--1938 work-potentials as redistributed by December 1942

In constructing Figure 1, which shows the relative work-potentials for various major world-areas (as of 1938), the writer arbitrarily assumed that each population of ten million people could, under energy-conditions, be potentially productive of five million man-years of work. It was further assumed that one horse or mule (or camel) had the "work-capacity" of eight average human manual laborers, and that one mechanical "horse-power year" (of fuel or hydro-electric energy) could also be converted to "man-power years of work-potential" by use of a factor of approximately 12.

Figure 2 shows how the control of potentials in 1938 had been shifted by the end of 1942--due to Axis victories--though it does not show how much national energy-outputs had been stepped up between 1938 and 1943--since many of the war-year figures needed are not now available. From Figure 2 it is clearly evident why, as of 1942, China was not able to offer a more active resistance to Japan, and it is also obvious that Germany had established a great superiority of potential over Britain and the Union of Soviet Socialist Republics. Indeed it seems practically certain that if the Germans had taken Britain immediately after Dunkirk they might soon have established as great a relative "power"-advantage over the United States, as Japan has had relative to China since 1942.

In constructing Figure 3 the writer has made several assumptions, as follows: (1) That postwar reconstruction can be effectively begun at least by 1948; (2) that the postwar international organizational arrangements for mutual benefit will have been so drawn as to assure the greatest possible technologic cooperation between nations; and (3) that a concerted international effort will be made to obtain a maximum increase of the productive and transportation-capacities of all countries.

On these assumptions, and considering both the latent energy-resources, and the mining (or drilling) conditions in the various world-regions the writer has concluded: (1) That Russia should have about three times the work-potential in 1948 that she had in 1938; (2) that the United Kingdom's potential (owing to difficult coal-mining conditions) will be but little larger in 1958 than it was in 1938; (3) that energy-production from areas within the borders of prewar Germany will be only moderately larger than in 1938; (4) that the Near and Middle East will have shown considerable increases in Turkish coal-production, and even greater increases of oil-production within the Persian Gulf and Suez areas; (5) that both the "Southern-Asia" and "Latin-American" regions will have established 1958 energy-outputs greater than that of the United Kingdom (due largely to the development of Chinese coal, and of Latin-American oil); and (6) that the United States will be able to give effective

peace-time employment in 1958 to its present (1944) war-time potential for energy-production--with the further proviso that our present production of coal can be considerably expanded by 1958--if that should become necessary.

With reference to Figure 3 it should be stated in passing (1) that even the most richly-endowed of all the "world-regions" (the Union of Soviet Socialist Republics and the United States) are lacking in supplies of various strategic commodities and raw materials, (2) that Latin-American developments will be handicapped by the great scarcity of good coking-coal in South America--unless counterbalancing interregional arrangements are worked out, and (3) that within the "West Mediterranean", "Near and Middle East", "Indian", "Southeast Asian", and "Northwest", "Central" and "Southeast European" areas the local standards of living can be greatly improved, if the

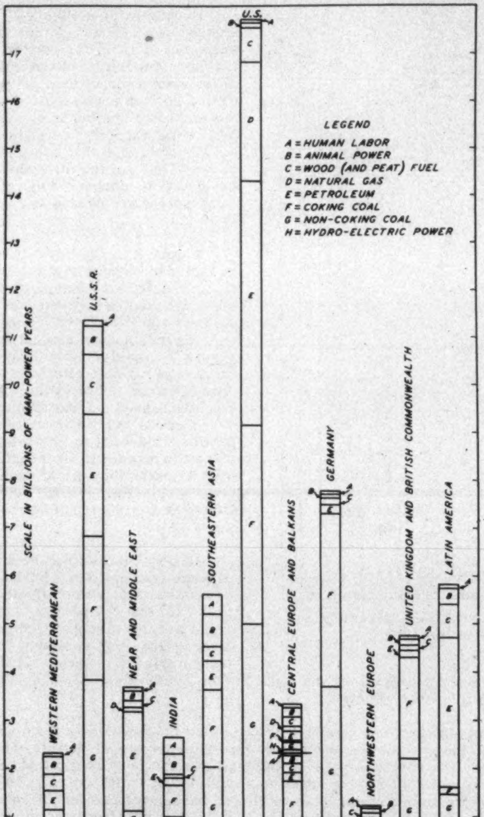


Fig. 3--World work-potentials which can be reasonably expected as of 1958

several regional groups concerned decide to take part in a cooperative development of their respective (regional) resources. It is also clear that due to geographic position and recently-developed modern weapons, the peoples of both the United Kingdom and of the area of prewar Germany will continue to occupy positions of acute industrial and military insecurity and instability from now on, unless the necessary consents can be had for the formation of natural regional constitutional federations, which can, in turn, be properly fitted into the framework of an effective world-wide "United Nations" organization.

In order to give a graphic description of some of the human problems which cry for thorough consideration (and constructive treatment) during future international conferences, Figure 4 has been constructed to show the per-capita work-potentials of different regions--since such per-capita figures provide a rough index to the relative standards of living of the world's different peoples.

In Figure 4 national populations have been plotted to scale as horizontal coordinates, and manpower years of work-potential per capita have been plotted vertically--these latter values ranging

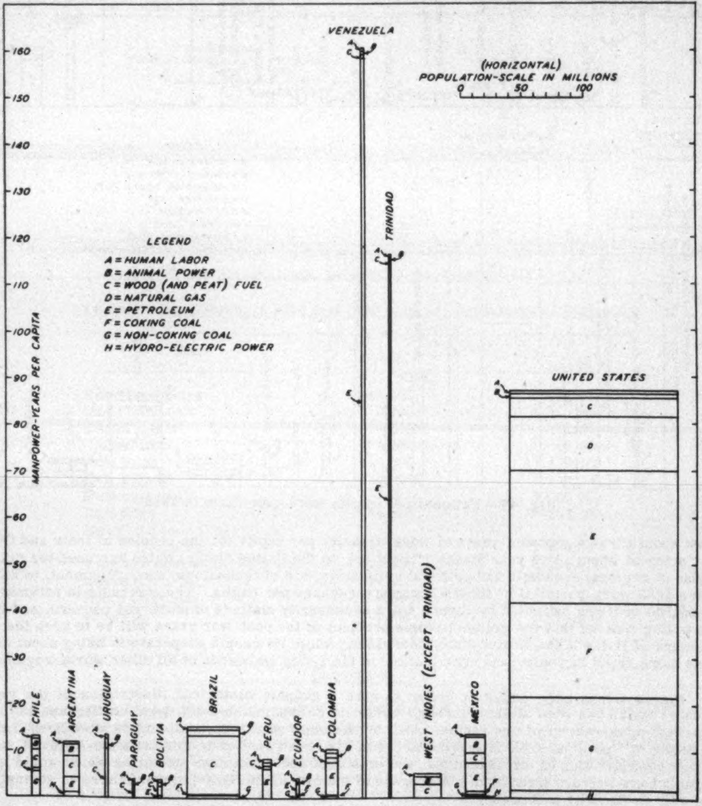


Fig. 4A--National per-capita work-potentials in 1938

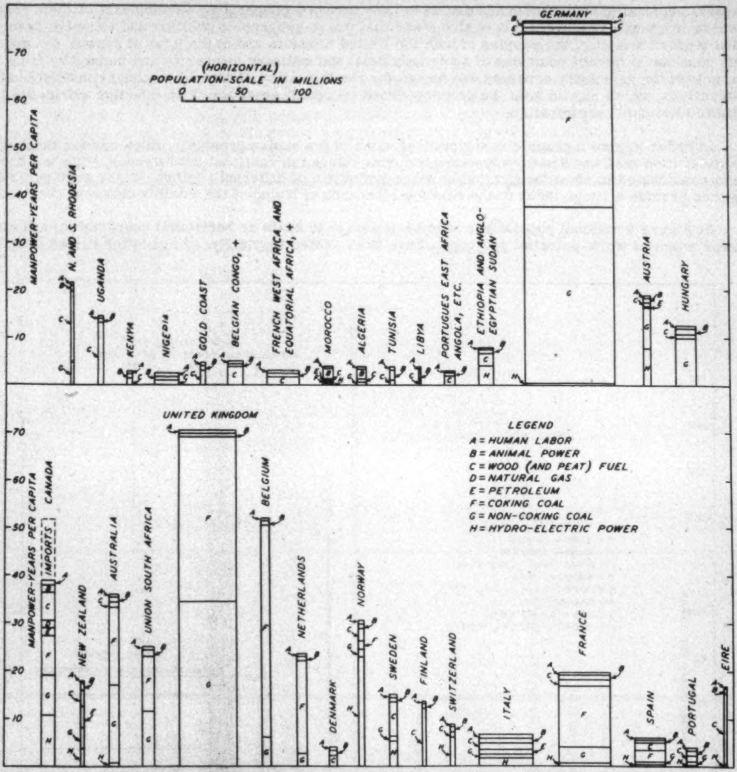
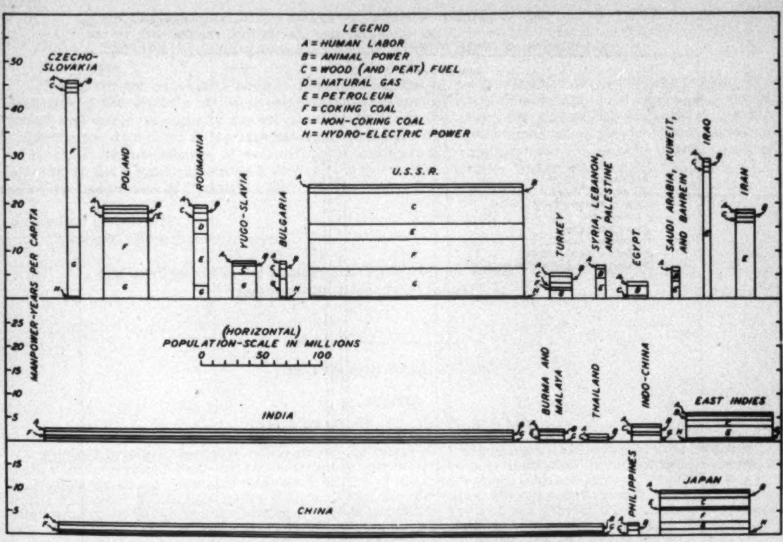


Fig. 4B--National per-capita work-potentials in 1938

from about three manpower-years of work-capacity per capita for the peoples of India and China (for many of whom a bad year means starvation) to the United States, which has used the principles of regional economic and political unification, and of technologic encouragement, to establish a 1938 work-potential of about 87 manpower-years per capita. The contrasts in national standards of living indicated by Figure 4 are necessarily matters of universal concern, and it is the writer's belief that the greatest single problem of the post-war years will be to keep the standard of living in the United States increasing, while its people cooperate to bring about an even more rapid increase (and equalization) of the living standards of all other world-regions.

Figure 5 has been added, in order to give a graphic historical illustration of the great success which has been attained through economic collaboration and federal unification, in the practical advancement of one region. And, by contrast, what the results might have been if the principle of "political self-determination" had also been applied in this instance--without sufficient consideration of, or regard for, the economic and "security" penalties which would inescapably have accrued from such a disregard of the old maxim that "in union there is strength" (as well as security and peace).



Figs. 4C and 4D--National per-capita work-potentials in 1938

Table 1--Populations in 1790 and 1940 used in preparation of Figure 5

State	Population in	
	1790	1940
New Hampshire	142,000	492,000
Massachusetts	379,000	4,317,000
Rhode Island	69,000	713,000
Connecticut	238,000	1,709,000
New York	340,000	13,479,000
New Jersey	184,000	4,160,000
Pennsylvania	434,000	9,900,000
Delaware	59,000	267,000
Maryland (and District of Columbia)	320,000	2,484,000
Virginia (and West Virginia)	748,000	4,580,000
North Carolina	394,000	3,572,000
South Carolina	249,000	1,900,000
Georgia	82,000	3,124,000
Totals	3,638,000	50,697,000

Conclusion

As prerequisites for the development of a sound solution for the present problems of our dynamic world it is clear that we must work out:

(1) A method for obtaining more adequate quantitative statements, descriptive both of our present and prospective national and regional power-potentials, and of our regional material and cultural needs and resources;

(2) A sound historical perspective on the forces and psychologies which have contributed to the present world-crisis; and

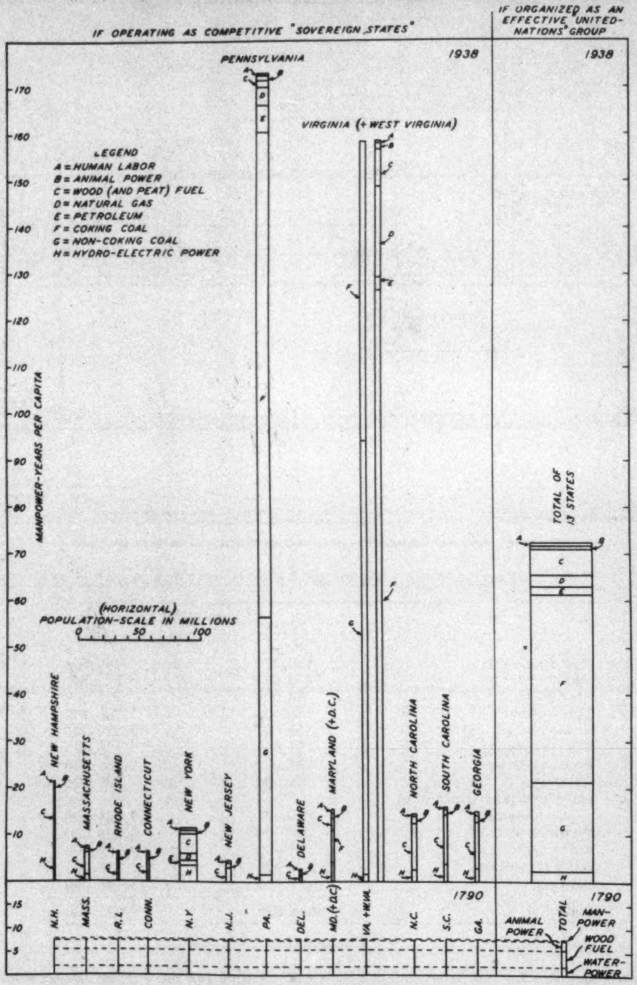


Fig. 5--Work-potentials of 13 "Sovereign States," 1790 and 1938 (fuel-energies credited to State producing that fuel)

(3) An adequate qualitative and quantitative evaluation of the current trends in social, religious, industrial, and strategic affairs, which must be properly allowed for, if our hopes for a just and durable peace are to be realized.

Moreover, we especially need to realize that, due to the irregular and uneven geographic distribution of the world's major sources of natural energies and of strategic raw materials, world-peace and world-prosperity cannot possibly be attained without the immediate creation of a world-organization dedicated to the improvement of the living conditions of all peoples, to the assurance of an effective interchange of scientific and technical information--for the benefit and security of all, and to the establishment of a World-Charter or Constitution under which there will be an effective guarantee of "justice under law".

Princeton University,
Princeton, New Jersey

(Manuscript received January 31, 1945, and as finally revised, May 5, 1945; open for discussion until January 1, 1946.)

NOTES AND PERSONALIA

NOTES

(See also pp. 12, 27, 36, 82, and 128)

Finnish Isostatic Institute--The continued interest of geodesists and geophysicists in their work and determination to carry on under all circumstances is indicated in recent letters from *W. Heiskanen* of the Isostatic Reduction Office of the International Association of Geodesy, Helsinki, Finland. Heiskanen states that, although the Technical University has been bombarded three times, lectures are still being held and scientific work of the Isostatic Institute is being carried on despite the fact that all of his assistants have been at the front three and four years and he has had no help from the International Association of Geodesy. Three young scientists have written their dissertations during the war period and the Institute's publications have increased to 13. Finnish institutions have given substantial financial aid to the Institute at a time when it was much needed. Heiskanen reports that *Bonsdorff*, *Keränen*, *Hirvonen*, and *Pesonen* are well, and that all now live in Helsinki; he states that they are now working on the continental undulations of the geoid and that *Tanni* has already spent three years on this work.

Annales de Géophysique--The first number (August, 1944) of Volume 1 of the *Annales de Géophysique* was received in the United States early in 1945. The *Annales* are published by the Société de la Revue d'Optique Théorique et Instrumentale of Paris under the directorship of *Jean Coulomb*, Director of the Institute de Physique du Globe and Professor at the University of Paris. This first issue contains original articles dealing with various aspects of the wide field of geophysics as is evident from an inspection of the leading articles, among which are: The spectrum of the night sky in the blue and violet regions; Indirect measurements of the density of rocks by means of the gravimeter; On the principles of the measurement of ion-conductivity of the air by means of dispersion-apparatus; Geomagnetic researches on the volcanic flows of Auvergne; Investigations of the radiation of sodium in the light of the twilight- and night-sky. There are also sections entitled "Notes from Laboratories" and "Bibliographic Reviews"--the latter restricted to important publications coming to the attention of the *Annales*. Printed in clear type on a page 27.5 by 22 cm, this new journal makes an excellent impression commensurate with the valuable articles which it contains.

Report on resolutions of the International Meteorological Organization--The Secrétariat of the International Meteorological Organization has announced the publication of the "Répertoire des résolutions de l'Organisation Internationale." The second edition of the "Répertoire" (Internationaler Meteorologischer Kodex) revised by *G. Hellmann*, appeared in 1911. In 1919 the English edition was brought up to date by the insertion of typewritten pages.

The intensity of international cooperation, increasing from year to year since 1919, has made a new edition of the "Répertoire" more and more necessary. The Secrétariat, in collaboration with a sub-committee consisting of *E. van Everdingen*, *D. la Cour*, and *E. Gold*, completed the project for presentation at the meeting of the Committee at Berlin in 1939. The "Répertoire" was edited almost wholly by the Secrétariat and is No. 50 (A31) in the series of the publications of the International Meteorological Organization. It may be obtained from the Secrétariat de l'Organisation Météorologique Internationale, Rue Etraz 5, Lausanne, Switzerland, at the following prices: Edition A (loose-leaf cover), 16 Swiss francs; edition B (paper cover), 12 Swiss francs. It is in 8vo and contains xvi + 485 pp.

NOTES AND PERSONALIA

NOTES (See also pp. 11, 27, 32, 36, 82, and 128)

Official insignia, 220th Anniversary Russian Academy of Sciences

Two Hundred and Twentieth Anniversary of the Russian Academy of Sciences--The Soviet Government celebrated, during June 15-30, 1945, the Two Hundred and Twentieth Anniversary of the Russian Academy of Sciences which was found in 1725 by Peter I. The celebration was held in Moscow and Leningrad, and was International in character. About 40 leading American scientists were invited, though only 17 were able to attend. Among invited Members of the American Geophysical Union were James E. Church (President of the Section of Hydrology), F. W. Reichelderfer (President of the Section of Meteorology), Merrill Bernard, A. Nadai, C.-G. Rossby, and Theodor von Kármán (those Members invited who could not attend were Walter S. Adams, Walter B. Cannon, A. H. Compton, and Robert A. Millikan). Most of the American party left New York by airplane on June 10, going by way of Newfoundland, the Azores, Casa Blanca, Cairo, and Teheran, arriving in Moscow on June 14; they left Moscow July 2 by way of Siberia and reached New York July 8. The guests visited numerous scientific institutes of the Academy both in Moscow and Leningrad, were on the Tribune of Red Square before the Kremlin for the Peace Day parade on June 24, and were banqueted in the Kremlin on Stalin Day on June 30. Excellent contacts for renewal of International scientific cooperation both with Russians and others were established.

International Union of Geodesy and Geophysics--Communications from abroad indicate considerable interest in the early revival of the activity of the International Union of Geodesy and Geophysics. It is tentatively planned to hold a meeting of the Union's Executive Committee in England late in 1945 or early in 1946.

Two volumes on Geophysics are being issued in war-torn Greece to commemorate the twenty-fifth anniversary of the career of Dr. Nicholas Critikos, Meteorologist and Seismologist.

The Anglo-French Society of Sciences, founded in April, 1940, to bring about closer liaison between French and British scientists, but dormant during the occupation of France, held its first conference in London, January 20, 1945. The general subject of the conference was "The solid state."

In Britian, the Royal Society has appointed a series of committees to advise on the requirements for fundamental researches in geophysics, biology, chemistry, and geography in the post-war period.

The activities of the French National Committee of Geodesy and Geophysics in France during the days of the occupation are indicated by five publications recently received here: Instructions Hydrologiques (Comité National Francais de Géodésie et Géophysique, Section d'Hydrologie Scientifique, Paris) 1940; Parts I (1941), II (1941), and III (1943) of the reports of the Commission du Bassin de la Seine (Section d'Hydrologie Scientifique, Comité National Francais, Union Géodésique et Géophysique Internationale); and first issue of Annales de Geophysique.

Physics of the Earth Series--The National Research Council advises that two volumes of the Physics of the Earth Series, which were sponsored by the Division of Physical Sciences, have sold well. Volume VIII, "Terrestrial magnetism and electricity" (x + 794 pp), published in 1939 by the McGraw-Hill Book Company, Inc., with the aid of the Council's subsidy of $2,500, has returned over half of this in royalties, while volume IX, "Hydrology" (xi + 712 pp), published in 1942 by the same Company, with a subsidy of $2,000, has returned over 85 per cent.

Geophysics in the National Academy of Sciences--The National Academy of Sciences elected, April 24, 1945, four Members of the American Geophysical Union to its membership, namely, Francis W. Reichelderfer (Chief of the United States Weather Bureau, and President of the Section of Meteorology), Harald U. Sverdrup (Director, Scripps Institution of Oceanography, and President of the Section of Oceanography), and Beno Gutenberg (Professor of Geophysics at California Institute of Technology)--all as geophysicists--and William W. Rubey (United States Geological Survey) as a geologist. Harold Jeffreys, Corresponding Member of the Union at St. John's College, Cambridge University, Cambridge, England, was elected a Foreign Associate of the Academy because of his preeminence in geophysics.

The Temporary Nominating Group on Geophysics, with 28 members in the various sections of the Academy, has been continued for another three years to 1948. It is hoped that the Group may secure the election of five or six Members in addition to the seven already elected by 1947, and that then a formal Section of Geophysics may be added to the other sections of the Academy.

Transactions, American Geophysical Union Volume 26, Part I August, 1945

TRIANGULATION-DATUMS IN ALASKA

A. C. Poling

Abstract--The purpose of this paper is to enumerate the more important datums used in Alaska, to show how they were connected to the North American 1927 Datum and the changes involved, and to discuss theoretical problems encountered and the conditions under which the observations were made.

Alaska was purchased from Russia in 1867, and work was soon started on charting the coasts of the new possession. For many years the triangulation consisted of detached surveys at various points along the coast, each on an independent astronomic datum. They were made by hydrographic parties of the United States Coast and Geodetic Survey. The purpose of these surveys was to control the charts of the coast. A chart made on one datum was consistent in itself but as triangulation-surveys were expanded, datums overlapped, and shore-lines on charts using different datums would not fit properly. In order to have all charts consistent, it was desirable that all triangulation be placed on one datum. The most logical way to do this was to extend the North American Datum from the United States.

All the triangulation done in Alaska previous to 1916 was of third-order accuracy and was along the coast and inlets. Since 1871 many small isolated schemes have been observed, each being on its own astronomic datum. Each datum was based on an astronomic latitude, longitude, and azimuth at one or more stations.

In southeast Alaska at about the end of the year 1900, the triangulation consisted of nine different third-order schemes, each on its own datum. By the end of the following year, these different schemes of triangulation had been joined to form a continuous scheme on one datum. This was known as the Southeast Alaska Datum, and it was based on 32 astronomic latitudes and eight astronomic longitudes.

During the time that the triangulation was being done in southeast Alaska, many other parts of Alaska were also being triangulated and charted by the United States Coast and Geodetic Survey. In the vicinity of Norton Sound, a third-order triangulation-scheme was observed. This was on the St. Michael Datum of 1891, based on the St. Michael Astronomic Station.

Many third-order schemes of triangulation were observed along the Gulf of Alaska from Valdez to Anchorage to the south end of Kodiak Island. These triangulation-schemes were combined in the years 1898-1905 to form the Valdez Datum, based on astronomical observations at Orca Astronomic Station and Valdez Longitude-Station.

Third-order triangulation-schemes along the Alaskan Peninsula and the Aleutian Islands were combined in 1896 to form the Unalaska Datum. The basis of this datum was the astronomic latitude, longitude, and azimuth at Unalaska Astronomic Station.

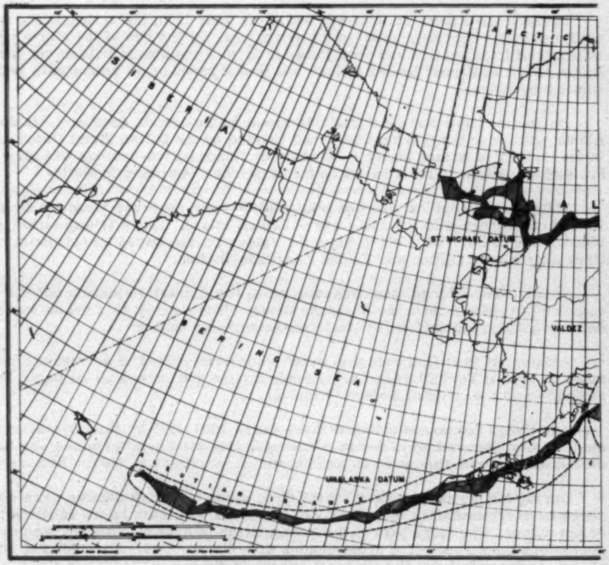
A datum at Port Clarence was based on determinations of astronomic latitude and longitude made in 1900 at Port Clarence Astronomic Station and served as the basis for the third-order triangulation on the coast of Seward Peninsula.

The Yukon Datum, established in the years 1907-1913 by the International Boundary Commission, was for the control of an arc of triangulation used in determining the boundary between Canada and Alaska, and was based on astronomic observations at Station Boundary on the Yukon River.

During the period of time in which these more extensive datums were established, small schemes of triangulation were executed in other areas, each based on its own independent astronomic datum. The large part of the triangulation in Alaska, however, was originally based on the six datums mentioned. The other datums were relatively unimportant and small in scope. Table 1 shows pertinent data for the six most important datums.

Table 1--Astronomical datums in Alaska

Datum	Date	Astronomical station	Latitude-determination		Longitude-determination		Azimuth	
			Instrument	Method	Instrument	Method	Instrument	Method
S. E. Alaska	1901	32 latitude 8 longitude	Various	Various	...... Various	.... Chronometric	Local azimuth-control	
Valdez	1898	Orca astronomical	Merid. trans.	Horrebow-Talcott	......	....	.....	......
	1905	Valdez longitude	......	......	Merid. trans.	Telegraphic comparison with Sitka	Merid. trans.	Micrometric
Unalaska	1896	Unalaska astronomical	Merid. trans.	Horrebow-Talcott	Merid. trans.	Chronometric comparison with Sitka	Merid. trans.	Micrometric
Yukon	1907	Boundary	Merid. trans.	Horrebow-Talcott	Merid. trans.	Adjustment Canadian telegraphic long.-net	Merid. trans.	Micrometric
St. Michael	1891	St. Michael astronomical	Merid. trans.	Horrebow-Talcott	Merid. trans.	Moon culminations, star occultations	Merid. trans.	Micrometric
Pt. Clarence	1900	Pt. Clarence astronomical	Vert. circle	Altitude Polaris	Merid. trans.	Chronometric comparison with Unalaska	.....	......



About 1915, plans were made to extend the North American Datum into southeast Alaska. The triangulation in southeast Alaska was not considered of sufficient accuracy to carry the North American Datum through that section, therefore a scheme of first-order triangulation was observed between the years 1916 and 1925 from the southern boundary of southeast Alaska to the vicinity of Skagway. At a conference between officials of the Geodetic Service of Canada and the United States Coast and Geodetic Survey, plans were formulated for the extension of the North American Datum from the State of Washington along the western coast of British Columbia to Dixon Entrance, connecting with the southeast Alaska triangulation. This arc of triangulation was completed by Canada in 1928, and the North American Datum was thus extended to Skagway, Alaska.

In the years 1922 to 1924, the United States Coast and Geodetic Survey worked on an arc of first-order triangulation which was to extend from Cook Inlet to Fairbanks. During these three seasons of work, each about two months in duration in the summer, the first-order arc was carried to Broad Pass, a distance of about 120 miles. No further first-order triangulation was observed by the United States Coast and Geodetic Survey in the interior of Alaska until 1941.

It became extremely important that all of the triangulation in Alaska should be placed on one datum. Because of glaciers and unstable topography along the coast of the Gulf of Alaska, it was impracticable to use that route for the triangulation-connection between southeast Alaska and the main part of Alaska. From the beginning, it was obvious that the connection would have to be made through the Yukon Territory, Canada. For various reasons, it was not possible to make any progress toward this goal until the present World War, when the connection was requested by the War Department. Many additional control-surveys in Alaska were also requested by that Department.

In 1941, therefore, funds were made available to the United States Coast and Geodetic Survey, and the work was greatly accelerated. By the end of the season of 1944, about 2,400 additional

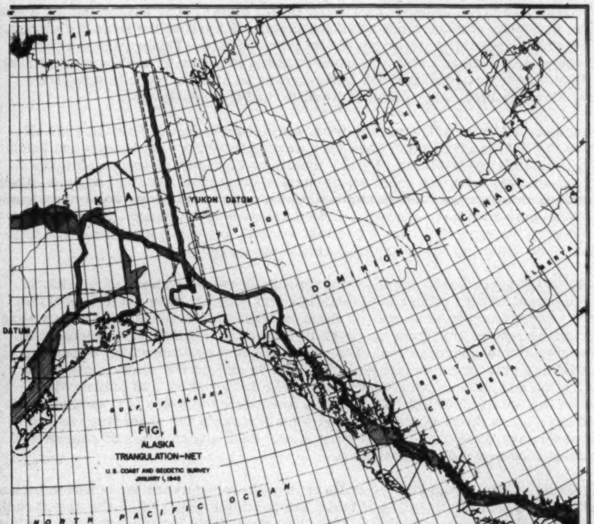


FIG. 1
ALASKA
TRIANGULATION-NET
U. S. COAST AND GEODETIC SURVEY
JANUARY 1, 1945

miles of control-triangulation were completed. The building of the Alaskan Military Highway in 1942 facilitated the running of the arc of triangulation connecting southeast with central Alaska. The new first-order triangulation-scheme extended from Skagway along the White Pass and Yukon Railway to Whitehorse, Canada, thence northwestward along the Alaskan Military Highway through Yukon Territory. It connected at the 141st meridian with the International Boundary Survey. From this point the triangulation followed the Tanana River to Big Delta, Alaska.

Another arc of triangulation was completed from Valdez along the Richardson Highway to Big Delta and Fairbanks, and thence southward along the Alaskan Railway to Nenana and Broad Pass and there connected with the arc of 1922-24. From Nenana an arc was extended along the Yukon River to Ruby and to a point near Kaltag, thence westward to Norton Sound.

An arc of triangulation was extended from the shore of Norton Sound north across Seward Peninsula to Kotzebue Sound and westward across Seward Peninsula to Cape Prince of Wales. Nome was connected from the north and from the east, thus completing a comprehensive and strong scheme of triangulation on Seward Peninsula. In south Alaska triangulation along the Glen Highway was observed between Anchorage and the Valdez-Fairbanks Arc.

The completion of these various arcs served to connect the Yukon, Valdez, St. Michael, and Port Clarence datums with the North American 1927 Datum. There remained the Unalaska Datum which had not been connected with the North American 1927 Datum due to a break in the continuity of triangulation along the Alaskan Peninsula between Wide Bay and Chignik Bay. In 1944 a first-order arc of triangulation was completed between Wide Bay and Chignik Bay and it then became possible to extend the North American 1927 Datum along the Aleutians as far as Kiska Island. Plans have been made to extend the triangulation to Attu Island in the near future. Thus the North American 1927 Datum will be extended from Meade's Ranch in central Kansas to the end of the Aleutians.

A comparison of the methods of field-work in 1922-24 with those in 1941-44 helps to explain the large amount of work accomplished in the past four years. The problems of transportation of men and equipment in Alaska are much greater than in the United States. The season during which triangulation can be done in Alaska extends from about the middle of April to the first of October, with many days of bad weather, especially in the months of June and July. Triangulation-schemes are made to follow the routes of roads and railways when possible in order to facilitate movement of supplies and men. Since there are few highways and railways in Alaska, much triangulation had to be observed along river valleys under difficult conditions of transportation.

The supplies and equipment for the triangulation from Anchorage to Broad Pass in 1922-24 were shipped part way on the Alaskan Railway. Then they were carried on pack horses and back-packed by the men to the triangulation-stations. Due to conditions of snow and ice, which made traveling difficult for pack horses, the work could not be started until about the first of June. Much time was consumed traveling between the triangulation-stations, and observations were often hampered by rain and fog. Instances have been recorded of food supplies (even though cached by experienced men) being eaten by wolves. Much time was lost in replacing these supplies. The difficulties of transportation made the progress of triangulation necessarily slow.

In the years 1941-44, trucks were used for the first time along existing roads in Alaska, in transporting men and equipment. Light rubber boats easily carried by the men made it possible for them to cross rivers readily, except when ice- or flood-conditions interfered. Airplanes were also used for the first time on Alaska triangulation-work to transport supplies and equipment to places which were otherwise almost inaccessible. The use of airplanes advanced the observing season to about the middle of April, since the planes could land on skis in the snow. Late in the season, when the snow had melted, planes using pontoons landed on the lakes, and planes with wheels were used between the small airfields. Thus it was a matter of minutes to transport men and equipment to points near the stations when conditions were favorable for observing, as compared to days of travel necessary when pack horses were used. Back-packing was of course still necessary between airplane landings and the stations.

In 1944, two triangulation-parties made use of radio transmitter-receivers for communication between observing parties. Reports of the chiefs of these two parties highly praise the use of radio communication. Except for a limited use of radio in 1941, communication between stations had previously been by abbreviations in International Morse Code transmitted by means of lights at the stations. This was necessarily slow and unreliable because of the limited darkness in Alaska during the summer months. With the aid of radio communication, a chief of party is in constant touch with each observing party and results of observations are quickly known. The computer can then make angle- and side-checks of the triangulation and determine whether reobservations are necessary. This use of radio saves time ordinarily consumed in the reoccupation of stations.

Since the completion of the field-work of the past four years all of the triangulation in the interior of Alaska has been adjusted on the North American 1927 Datum. In addition, preliminary positions on the North American 1927 Datum have been computed from Anchorage along the Alaskan Peninsula and the Aleutian Islands to Kiska Island.

In the adjustment of the main scheme of triangulation in Alaska, 26 measured base-lines and 18 astronomic azimuths were used. The bases were placed at an average spacing of ten quadrilaterals while the average spacing of the azimuths was 11 quadrilaterals. The triangulation is thus well controlled in azimuth and length and will form a good basis for future triangulation.

A comparison of the more important datums in Alaska with the North American 1927 Datum is tabulated in Table 2.

Table 2--Comparison of more important datums in Alaska

Station	Original datum	Latitude, longitude	N. A. 1927 Datum	Datum-change
		° ′ ″	″	″
Ken	S. E. Alaska	54 54 34.785	39.251	+ 4.466
		131 59 44.326	38.841	- 5.485
Hudson	Valdez	61 51 56.73	66.75	+10.02
		145 40 46.97	17.22	-29.75
Kumlik	Unalaska	56 38 27.69	22.31*	- 5.38
		157 24 41.81	38.95*	- 2.86
Airs (I.B.C.)	Yukon	62 34 42.335	44.278	+ 1.943
		141 06 12.267	09.799	- 2.468
Flat Point	St. Michael	63 37 27.939	25.852	- 2.087
		161 00 13.768	36.732	+22.964
Mound	Port Clarence	65 09 24.665	24.192	- 0.473
		166 56 21.883	46.340	+24.457

* Unadjusted position

A point of interest connected with the Alaska triangulation is the large deflections of the vertical found in different localities. At some stations these deflections have an appreciable effect on observed horizontal directions, where the angle of elevation between two stations is large. As an example, at the Astronomic Station Sheep Astro, the horizontal direction from Sheep Astro to Nuska was in error by $1''.88$ due to the deflection of the vertical at Sheep Astro. Correction to direction for deflection of vertical = $(\xi \sin\alpha + \eta \cos\alpha) \tan e$, where $\xi = (\varphi_A - \varphi_G)$, $\eta = (\lambda_A - \lambda_G) \cos\varphi$, α = azimuth of line, and e = angle of elevation of line.

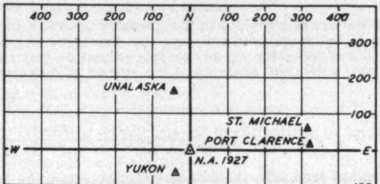


Fig. 2--Comparison of datums, meters

Example: Sheep Astro to Nuska

$(\varphi_A - \varphi_G) = -8''.14$, $(\lambda_A - \lambda_G) = +23''.53$, and $(\lambda_A - \lambda_G)\cos\varphi = +11''.12$

$\alpha = 323°01'20''$, $\sin\alpha = -0.601505$, $\cos\alpha = +0.798869$

$e = +7°45'05''$, $\tan e = +0.136119$

Correction $= +1''.88$

It is probable that the horizontal directions at many stations are affected by the deflection of the vertical but as the astronomic latitude and longitude are necessary in computing this effect at any station, it can be evaluated at only a few such stations.

The future economic importance of Alaska, as well as its use as a route for world-airways, makes it necessary that adequate maps be provided. Many Alaskan maps have been inaccurate in the past and some sections of Alaska were unsurveyed. It has been found that some peaks were shown as much as a mile in error in position, while other peaks have been omitted altogether. By the use of precise triangulation-control, in conjunction with aerial photographs, the maps of the future can be made much more accurate. Accurate airway-charts will take much of the hazard out of flying over Alaska.

U. S. Coast and Geodetic Survey,
Washington 25, D. C.

(Manuscript received May 19, 1945, for presentation at Twenty-Sixth Annual Meeting at Washington, D. C., June 1, 1945; open for discussion until January 1, 1946.)

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

(See also pp. 58, 68, 90, and 126)

J. BOULANGER: On the accuracy of the measurements of the anomaly of gravitation with the aid of gravitational variometers. Bull. Acad. Sci., U. S. S. R., Sér. Géog. Géophys., v. 8, no. 5, pp. 285-291, 1944.

In the geological interpretation of gravimetric surveys it is useful to estimate the reality of the anomaly in comparison with a possible accumulation of errors of measurements. This paper includes a short summary of the solution of the problem raised and two formulas for the calculation of the maximum of the average and relative error of the intensity of the anomaly. The author develops the formulas, assuming an equal accuracy of all observations of a given survey with a uniform distribution of the variometrical points. The discrepancy in closed contours along which the integration of the gradients of gravity is carried out serves as a criterion for the accuracy of the observations.

The calculation of the errors of intensity of the anomaly in the Ishim-Bay Region of the Ural foreland showed, according to the proposed formulas, that there was not great accuracy of the variometrical survey as anomalies of intensity one to two mgl cannot be regarded as satisfactorily measured. It is necessary to give a detailed analysis of the errors of measurements when interpreting them.

English summary by author

D. N. KHRAMOV: Experiment of application of the hypothesis of partial isostatic compensation. Bull. Acad. Sci., U. S. S. R., Sér. Géog. Géophys., v. 8, no. 5, pp. 281-284, 1944.

Following the proposition of MALKIN, the author introduces into the isostatic calculations a new parameter ϵ, the degree of compensation. The criterion for the true choice of ϵ is the condition of minimum for the sum of squares of the declination of isostatic anomaly from average values. The gravimetrical data of the Caucasus were subjected to a new treatment using the data from the corresponding work of HEISKANEN. The calculations showed that the hypothesis of the partial isostatic compensation agrees no worse than the results using hypothesis of absolute compensation, and that the Caucasus is compensated approximately one-half.

English summary by author

Transactions, American Geophysical Union Volume 26, Part I August, 1945

GURLEY FOUR-INCH ARMY THEODOLITE

Harold R. Larsen

Abstract--An optical-reading theodolite has been developed for military purposes by W. and ~~L. E. GURLEY~~. This new theodolite is comparable in size to the WILD and TAVISTOCK theodolites. A complete description of the new instrument furnishes the basis for a comparison with the most important features of the WILD, TAVISTOCK, and PARKHURST theodolites. The speed and convenience in use and ruggedness and compactness in design make the instrument highly desirable for many types of surveys.

In 1940 the United States Army Engineers circulated among American instrument-manufacturers a proposal to undertake the development of a light, compact, precise, universal theodolite, especially suited for military purposes. This invitation was accepted by W. and L. E. GURLEY, and, in the same year, plans were laid to proceed with the development of such an instrument.

The objective was a five-second theodolite, but as the development continued, it was possible to turn it into a one-second instrument. The project originally was broken into two parts, namely, (1) the preparation of the miniature, precise, graduated circles, and (2) the actual design and manufacture of the model theodolites.

The circle-problem was ably handled by the National Bureau of Standards, and the work done in developing them is a story all in itself. The final product, by actual comparative tests, is among the most accurate produced in the world.

Later on, the University of Rochester designed a special telescope for the theodolite, original models of which were executed in the shops of W. and L. E. GURLEY.

All work on this theodolite was correlated and supervised by the Engineer Board of the Corps of Engineers, United States Army, Fort Belvoir, Virginia.

Several models of theodolites were constructed around the basic optical reading-system that was designed in the Engineering Department of W. and L. E. GURLEY. The final product illustrated in Figure 1 has the following general characteristics:

Total height, 13 inches
Greatest diametrical dimension, 7 inches
Size of horizontal and vertical limbs, 4 inches
Weight of instrument, 13-1/4 pounds
Weight of instrument and tripod, 28 pounds
Least reading for both horizontal and vertical limbs, one second
(can be estimated to 1/10 second)
All motions completely enclosed
Equipped with optical plummet
Telescope, inverting and internal focusing, power 27
- Eye distance, 7 mm
- Clear aperture, 40 mm
- Resolving power, 4 seconds
- Interchangeable glass reticle with horizontal and vertical stadia
- Length, 6-1/2 inches overall

Provision for night lighting

Some idea of the amount of work done in developing the theodolite can be derived from a cross-sectional view illustrated in Figure 2. It is obvious that the problem was almost as much a mechanical one as it was optical.

The method of reading the circles was selected after studying two basic means of reading graduated circles. The first method referred to consists of reading the angular displacement of two diametrically opposite portions of a limb. The devices employed for measuring the actual angular displacements will vary according to the detail requirements and include ordinary indices, verniers, and microscopes, fitted either with graduated glass scales or "Filar" micrometer-eyepieces. The other method referred to consists of measuring the relative angular displacement of two diametrically opposite portions of a limb. This method is described in Letters Patent granted to HEINRICH WILD of Switzerland as early as 1908. This method was finally selected as offering more advantages to the design of a small theodolite suitable for military purposes.

The actual principle involved in this system can be understood more readily by examining Figure 3. It is apparent that optical means are required to produce two juxtaposed images of diametrically opposite portions of the limb in order that measurement of relative angular displacement can be effected. Actually, in reading angles by means of this device, the value is that of the graduation near the index plus one-half of the relative displacement of the two opposite graduations. In the illustration the angle is $[0 - \theta/2]$.

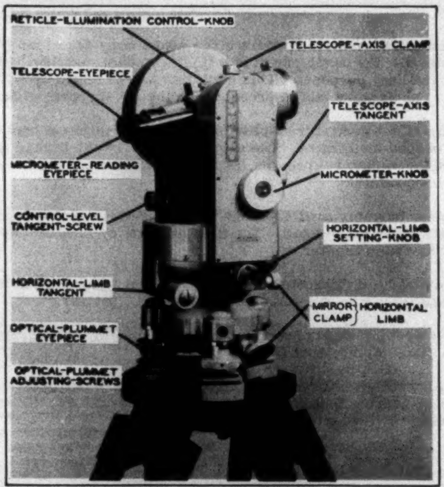


Fig. 1--Parts of Gurley theodolite

There are numerous methods by which the relative displacement of the graduations can be measured. If the angular separation is not too great, the angular increments are equal, for all practical purposes, to linear increments and the measurement of the displacements can be effected by linear measuring devices. The requirements of such a device suited to this problem are rather critical, however, when one considers that, on a four-inch limb, a single second of arc represents approximately 0.000009 inch. Such devices as applied to optical theodolites are frequently referred to as "optical micrometers" and, hereafter, this nomenclature will be used.

In the GURLEY theodolite, the optical micrometer basic principles were suggested by JOHN B. SONDERMAN, Optical Engineer of W. and L. E. GURLEY, who also performed all detail computations on lens and prism components involved in the theodolite. This principle is illustrated in Figure 4, where in (A) a light-ray is refracted by a wedge-prism, the amount of refraction being determined by the included angle and the index of refraction of the glass. Means are provided to bring the light to a focus at the focal plane F and the displacement of the ray from its original projected path is proportional to the distance of the wedge-prism from the focal plane. It can also be seen that movements of the prism parallel to the light-ray will cause the displacement of the ray at the focal plane to vary directly with the movement of the prism. Consequently, by attaching a linear

scale directly to the carriage supporting the wedge-prism, minute measurements of displacements of a light-ray can be made.

Since there are two light-paths--one from each side of the limb--to consider, the optical micrometer is provided with a pair of wedge-prisms placed in reversed position with respect to one another, and the rays from each side are made to pass through their respective prisms. The reference-point for all measurements is that position of the limb where opposite graduations appear in line with one another. This is termed a "coincidence". How this is accomplished is illustrated in (B) and (C) of Figure 4. (B) indicates the relative position of limb-images before actual measurements are taken by the optical micrometer. It should be noted that the images are in "coincidence" with the scale-reading zero. After the wedge-prisms are moved through a scale-reading of ten minutes, coincidence is again obtained, and is illustrated in (C).

The GURLEY theodolite has four-inch limbs divided to 20-minute intervals, and the micrometer scale is ten minutes long and divided into 600 parts corresponding to single seconds. The

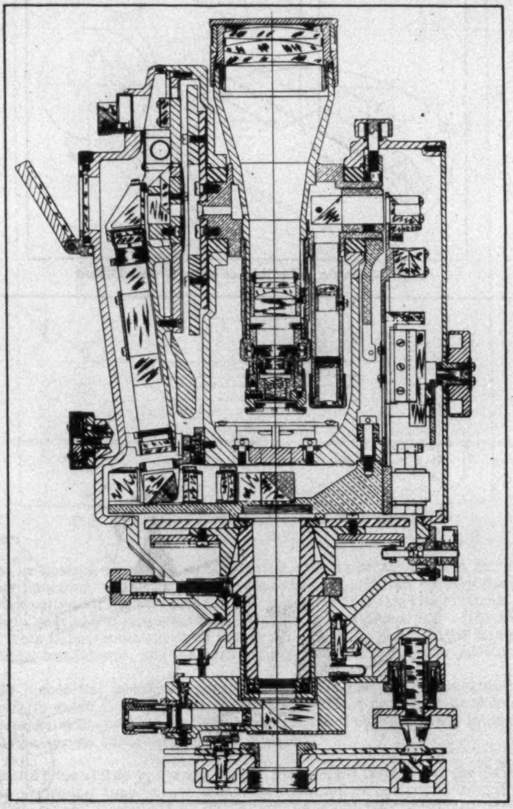


Fig. 2--Cross-section Gurley theodolite

micrometer need only cover an interval of ten minutes, since a coincidence of limb-graduations is had each ten-minute displacement of limb, due to the fact that the motions of the limb-images are in opposite directions.

The complete optical system of the theodolite is laid out schematically in Figure 5 to show how control over the light-rays is exercised and to show the relation of the optical system to various parts of the theodolite. The limb is on an optical reflecting surface; consequently, special illumination means are provided. The microscope through which the readings are made is attached to the axis bar of the main telescope so that observations and readings can be made with a minimum amount of time and effort.

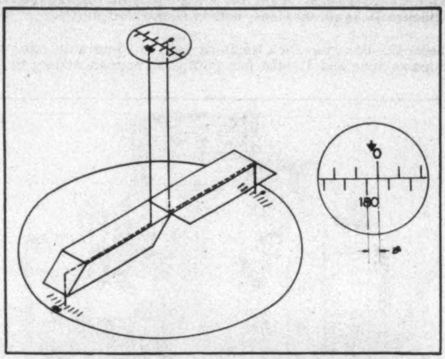


Fig. 3--Basic principle of optical theodolites

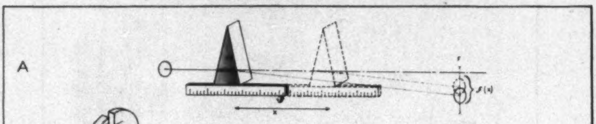


Fig. 4--Principle of Gurley optical micrometer

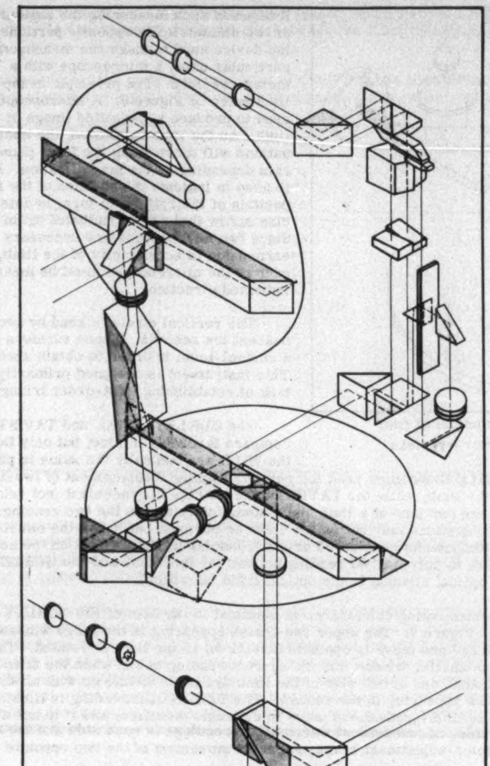


Fig. 5--Optical system, Gurley 4-inch theodolite

The altitude- or control-level is also illustrated with its prism-system for reading one end of the bubble against the other, and is attached to the same support that carries the two circle-reading prisms. Mounting the vial in this fashion and enclosing it within the vertical-circle housing has shown that it is possible to make vertical-circle observations within ±2 seconds of the indicated circle-reading. This includes the error of observation made in pointing the telescope, the error in adjusting the bubble-coincidence, and the error of setting and reading the optical micrometer.

The GURLEY theodolite, insofar as sensitivity is concerned, is comparable to the PARKHURST first-order theodolite which is used by the United States Coast and Geodetic Survey in establishing its first-order triangulation-nets, to the WILD one-second theodolite made in Switzerland, and to the TAVISTOCK one-second theodolite made in England.

The PARKHURST theodolite is a much larger instrument than either the GURLEY, WILD, or TAVISTOCK; its horizontal limb is nine inches in diameter as compared to approximately four inches for the other three. It also works on a principle which was described earlier in this paper.

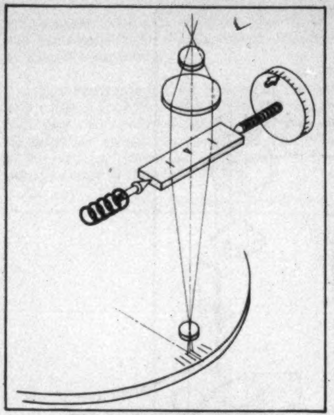


Fig. 6--Principle of filar micrometer-eyepiece

It depends upon measuring the angular displacement of two diametrically opposite portions of a limb, and the device used to make the measurements is, in this particular case, a microscope with a "Filar" micrometer-eyepiece. The principle of the microscope is illustrated in Figure 6. A microscope-objective is used to produce a magnified image of a division of the limb. As the limb is rotated, the images of the graduations will move along the focal plane at an increased rate depending on the magnification. A movable reticle is used to indicate the position of the image, and the position of the reticle, in turn, is determined by a precise screw that has a graduated drum attached to it. Since two microscopes are necessary to eliminate errors due to eccentricity of the limb, readings from each of the microscopes must be meaned to obtain an indicated direction.

The vertical circle is read by two verniers to the nearest ten seconds. These verniers are adjustable to a control-level in order to obtain accurate elevations. This instrument is designed primarily for the single task of establishing first-order triangulation-nets.

The GURLEY, WILD, and TAVISTOCK theodolites compare favorably in size, but only the GURLEY and the WILD are basically the same in principle. The GURLEY and the WILD theodolites read the relative angular displacement of two diametrically opposite portions of a limb, while the TAVISTOCK reads the displacement (not relative) of two diametrically opposite portions of a limb and automatically means the two readings. The distinction between the two systems may not be too clear or obvious, but it has the effect of reducing the number of optical components considered critical, insofar as their effect on the accuracy of the reading is concerned, to only the two reading prisms for the WILD and the GURLEY, while in the TAVISTOCK each optical element in the optical train is critical.

The means of establishing coincidence is identical in the case of the GURLEY and the WILD and is illustrated in Figure 7. The upper two scales appearing in the large window are brought into optical coincidence and move in opposite directions as the limb is rotated. The micrometer-scale appears in the smaller window and the correct reading is had when the micrometer-scale is adjusted so that all divisions of one side of the limb are made to line up with all divisions on the other side of the limb appearing in the window. The TAVISTOCK reading is illustrated in Figure 8. In this case, opposite limb-graduations move in the same direction, and it is not a case of relative displacement but rather of independent micrometer-readings of each side and the mean value determined. Micrometer-adjustment causes apparent movement of the two opposite graduations

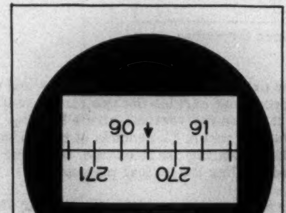


Fig. 7--Gurley reading-system

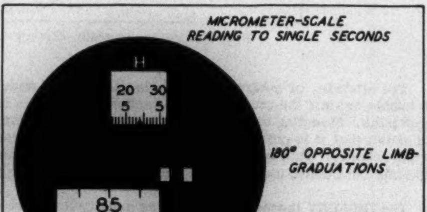

MICROMETER-SCALE READING TO SINGLE SECONDS
20 30
5 5
180° OPPOSITE LIMB-GRADUATIONS
85
LIMB-READING TO NEAREST 20 MINUTES
85° 25′ 24″

Fig. 8--Tavistock reading-system

appearing in the small window until they appear to be spaced equally about a fixed index. Eccentricity would have the effect of changing the light-gap between the fixed index and either of the two graduations.

The basic principles of the optical micrometer of the WILD are illustrated in Figure 9. The WILD micrometer consists of a plane-parallel glass element which, when rotated, displaces the path of a light-ray passing through it. The rotation of the element, in turn, is measured by a spiral cam to which is attached a circular scale. Since two optical paths, one from each side of the limb, must be measured simultaneously, two plane-parallels, side by side, operated by the same spiral cam but rotating in opposite directions, are used.

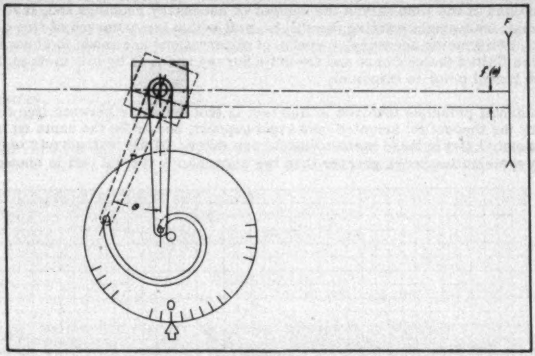


Fig. 9--Principle of Wild optical micrometer

The TAVISTOCK theodolite uses a wedge-prism in the micrometer and the displacement of it is measured by a rack and pinion (see Fig. 10), the pinion having a circular scale attached to it. This may seem very similar to the GURLEY micrometer, but the optical arrangement of the TAVISTOCK is such that the horizontal circle and the vertical circle each require a separate micrometer, whereas, in the GURLEY theodolite, only one micrometer is required for the two. Examination of the three micrometers described, show that the linkage between apparent image-movements and the scale-reading of the same are mechanical in nature, requiring mechanical precision, while in the GURLEY this linkage is optical in nature and mechanical precision at this point is not a factor.

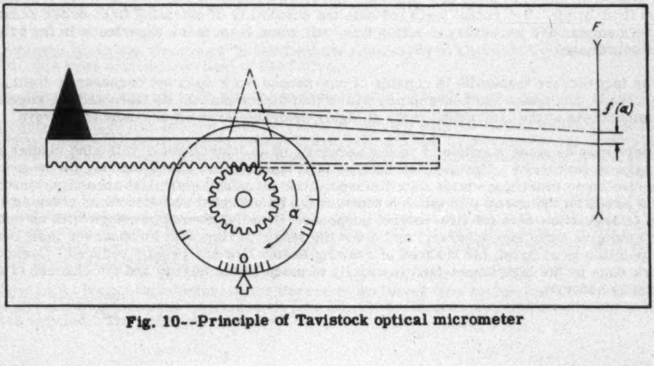


Fig. 10--Principle of Tavistock optical micrometer

The GURLEY, WILD, and TAVISTOCK theodolites are all considered universal instruments due to the fact that they are rather compact and can be used for practically any type of work. The sensitivity of the vertical circle, in combination with the control-level, permits accurate observations of elevation and, in combination with the precise horizontal-circle reading-system, astronomic fixes are possible. One of the chief military advantages of these instruments is the speed with which observations can be made. The optical plummet on the GURLEY and the WILD theodolites make possible rapid set-ups over a point in spite of the wind. The elimination of separate readings of opposite portions of the limb halves the number of necessary readings and, last of all, one is quite certain that, on a single pointing, he will be well within the accuracy of five seconds of the true direction. For greater accuracy, a series of observations are made in accordance with the procedure of the United States Coast and Geodetic Survey and it is by this method that all GURLEY theodolites are tested prior to shipment.

The fundamental principle involved in this test is that the angle between five fixed collimators, as measured by the theodolite, mounted on a rigid support, should be the same no matter on what part of the graduated circle these measurements are taken. Of all instruments tested, no single one has shown systematic errors greater than two seconds. A typical test is shown in Figure 11, and it shows that the maximum systematic error is 1.2 seconds. This is a tribute to the precision of the dividing of the circles done by the National Bureau of Standards, as well as the precision of the instrument itself.

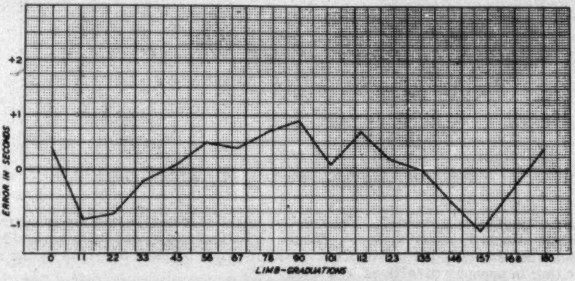


Fig. 11--Apparent mean graduation-error of opposite graduations as tested in instrument

Experience in using the instrument indicates that the probable error to be expected in pointing the telescope on a target is 0.5 second, while the error of establishing "coincidence" in the micrometer is no greater than one second.

It should be borne in mind that this instrument was designed for second-order triangulation and not first-order. Yet recent tests indicate the possibility of obtaining first-order accuracy. What refinements are necessary to attain this, will come from more experience in the actual use of the instrument.

The fact that the theodolite is capable of one-second work does not necessarily limit its use to this class. The speed and convenience with which directions can be taken and the ruggedness and compactness of the instrument make it highly desirable even on one-minute surveys.

There may be some question as to the necessity of an instrument of this kind insofar as military usage is concerned. The need for such an instrument is not based entirely on the precision obtainable, since repetitions made on a 20-second transit afford sufficient accuracy, but the real value is based on the speed with which a position can be occupied and directions obtained in establishing triangulation-nets for fire-control purposes. Usually several pointings with an instrument of this kind give sufficient accuracy, and since the length of time that an observer must occupy a single position is so brief, his chances of drawing enemy fire are greatly reduced. Consequently, the work done by the instrument-man is usually of much better quality and the chances of error are greatly reduced.

With the increased mobility and fluidity of modern warfare, it is essential that control-points be maintained as near the line of action as possible and, without instruments of this kind, it is practically impossible to carry on triangulation at the speed that is required in modern warfare. The mechanical and optical arrangements of the theodolite make it possible for the instrument-man to read both horizontal and vertical circles, as well as plate- and control-levels, all from the eye-end of the instrument. In addition, all controls are arranged for the greatest convenience in handling and, thereby, assist in speeding up operations.

The completion of this project represents an important step forward in American instrument-design, inasmuch as this is the first completely optical-reading theodolite to be designed and built in this hemisphere.

W. and L. E. Gurley,
Troy, New York

(Manuscript received May 24, 1945, for presentation at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until January 1, 1946.)

NOTES AND PERSONALIA

PERSONALIA

(See also pp. 11, 12, 32, 36, 82, and 128)

David Brunt, Fellow of the Royal Society and Professor of Meteorology at the Imperial College of Science and Technology, London, was recently awarded the Royal Medal by the Royal Society for his outstanding contributions in meteorology.

Kirk Bryan and Claude C. Albritton recently received honorable mention by the Foundation for the Study of Cycles for their paper entitled "Soil phenomena as evidence of climatic changes" [Amer. J. Sci., v. 241, pp. 717-752, 1943].

E. Bucher, Director of the Swiss Snow and Avalanche Research Institute in Switzerland, and Gerald Seligman in England are active in work on the physics of snow.

Harold Conkling, formerly Deputy State Engineer of California, has entered into private practice, specializing in hydrologic and hydraulic problems of ground-water and water-supplies, and in the economic problems involved.

Charles E. Deppermann and W. C. Repetti, both of the Manila Observatory, were released from Japanese concentration camps following our invasion of the Philippines and have returned to this country in connection with the reestablishment of the Observatory which was utterly destroyed. Contact has been reestablished with Andres O. Hizon of the Philippine Bureau of the United States Coast and Geodetic Survey.

Maurice Ewing has been appointed Associate Professor of Geophysics in the Department of Geology, Columbia University, to be effective on the completion of his war assignment at Woods Hole.

Lawrence M. Gould, Professor of Geology and Geography at Carleton College, Northfield, Minnesota, has been named President of the College.

Beno Gutenberg was recently elected to membership in the National Academy of Sciences.

Nicholas H. Heck has retired after 41 years of service with the United States Coast and Geodetic Survey. Since his graduation at Lehigh University in 1904, he has served the Survey in various capacities, namely, Hydrographic Engineer, Geomagnetician, Seismologist, and Scientific Adviser to the Director. From 1941 to 1942 he was Chief of the Division of Geomagnetism and Seismology, and was successively President of the Section of Oceanography of the American Geophysical Union (1924-26), President of the Section of Terrestrial Magnetism and Electricity (1926-29), President of the Section of Seismology (1929-32), and President of the Union (1935-38). He was the fourth recipient of the William Bowie Medal of the Union and has been active on the International Union of Geodesy and Geophysics, the Society of Sigma Xi, the American Society of Civil Engineers, and other organizations.

Thomas A. Jaggar was conferred the degree of doctor of laws by the University of Hawaii at its 34th annual commencement exercises on June 12, 1945. He gave the commencement address which was entitled "The great reversal."

PERSONALIA--Continued

Harold Jeffreys of St. John's College, Cambridge University, Cambridge, England, a Corresponding Member of the Union, was recently elected a Foreign Associate of the National Academy of Sciences.

O. T. Jones, Corresponding Member of the Union, and Professor Emeritus of Geology at the University of Cambridge, Cambridge, England, was recently the recipient of the Wollaston Medal, awarded by the Council of the Geological Society of Great Britain for fundamental contributions to knowledge concerning the stratigraphy of lower Palaezoic sedimentary rocks of Wales.

R. M. Leggette, formerly in charge of the United States Geological Survey's ground-water investigations in New York and New England, has opened an office as consultant in ground-water geology.

A. I. Levorsen has been appointed Professor of Geology and Executive Head of Department at Stanford University.

Walter C. Lowdermilk, President of the American Geophysical Union during 1941-44, delivered an interesting illustrated address before the Cosmos Club, Washington, D. C., on March 12, 1945, on the subject "Northwest China: Landscape, people, and customs."

O. Lütschg reports on activities in Switzerland during the last few years and is looking forward to a revival of international cooperation.

James B. Macelwane, Dean of the Institute of Geophysical Technology, St. Louis University, delivered the National Sigma Xi lecture on the subject "The interior of the Earth" at ceremonies in connection with the installation of a Chapter of the Society of Sigma Xi at Catholic University of America in Washington, D. C., on March 12, 1945.

Ch. Maurain, formerly Director of the Institut de Physique du Globe of Paris, has resigned from active service and Jean Coulomb is his successor. Work in geophysics is rapidly being reestablished in France.

F. W. Reichelderfer, C.-G. Rossby, and Merrill Bernard left in June to attend the 220th Anniversary of the founding of the Russian Academy of Sciences and to study Russian methods and techniques for meteorological and hydrological work. It will be recalled that about two years ago Russia sent a similar mission to this country [Trans. Amer. Geophys. Union, Pt. II, pp. 736-737, 1943].

F. W. Reichelderfer was recently elected to membership in the National Academy of Sciences.

Clarence J. Root, Meteorologist in Charge of the Detroit Station of the United States Weather Bureau since 1932, and in charge of the Springfield (Illinois) Station from 1911-32, retired March 31, 1945, after 45 years in the Bureau.

C.-G. Rossby was recently elected to Honorary Membership in the Institute of the Aeronautical Sciences.

William W. Rubey was recently elected to membership in the National Academy of Sciences.

R. Stonely presented the third of a series of lectures on January 12, 1945, for members of the British and Allied Armed Forces sponsored by the Royal Astronomical Society and the British Astronomical Association on the general subject of earthquakes. His lecture was a popular account of earthquakes and Earth waves.

Harald U. Sverdrup was recently elected to membership in the National Academy of Sciences.

R. J. Tipton has recently announced the formation of a partnership with E. H. Carter, a longtime member of his staff, under the firm name R. J. Tipton and Associates.

Parker Trask has been appointed Professor of Geology at the University of Wisconsin, effective in September 1945.

W. H. Twenhofel, Professor of Geology and Chairman of the Department at the University of Wisconsin, has recently retired.

Chester K. Wentworth has recently been elected Secretary-Treasurer of the Hawaiian Academy of Science. Other officers are Peter H. Buck, President, and Thomas A. Jaggar, Jr., Vice-President.

Transactions, American Geophysical Union Volume 26, Part I August, 1945

THEORY OF LARGEST VALUES APPLIED TO EARTHQUAKE MAGNITUDES

John M. Nordquist

(Contribution No. 375, Balch Graduate School of the Geological Sciences,
California Institute of Technology, Pasadena, California)

The theory of largest values [see 1, 2, of "References" at end of paper] requiring data on only the largest event in each of a number of equal time-intervals, recommended itself to the author as a possible way of describing the earthquake activity of a region. A preliminary analysis using the calendar month as the interval having demonstrated the applicability of the theory in this field, the author has investigated the feasibility of using still shorter intervals [3]. In the present paper the interval used is one-third of a month--the first day through the tenth, the eleventh through the twentieth, and the twenty-first to the end of the month. This interval therefore corresponds to that of one year used in flood-analyses. A compensating change has been made in the return-period scale (Fig. 2). Incomplete results of further analysis indicate that it is feasible to use a time-interval as short as five days.

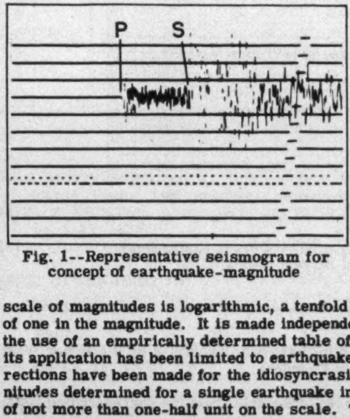


Fig. 1--Representative seismogram for concept of earthquake-magnitude

The concept of earthquake magnitude [4, 5, 6] is based on the largest amplitude in a seismogram recorded by a Wood-Anderson torsion seismometer (free period 0.8 sec, static magnification 2800, damping nearly critical). A representative record is shown in Figure 1, which is a typical record of an earthquake of magnitude 4-1/2 originating 48 miles from the recorder. The up-and-down displacement of the horizontal line represents the north-and-south motion of the ground at the instrument, magnified about 2500 times. The breaks in the line near the bottom of the Figure are the impulses, one second apart, of part of a radio time-signal. Recording speed of the original record (reproduction is reduced to about 2/3 of original) was 1 mm/sec. This instrument is standard at the Seismological Laboratory in Pasadena, California, and at six of its auxiliary stations. The scale of magnitudes is logarithmic, a tenfold increase in the amplitude corresponding to an increase of one in the magnitude. It is made independent of the distance from source to instrument through the use of an empirically determined table of recorded amplitude as a function of distance. So far, its application has been limited to earthquakes of "normal" focal depth (15 to 40 km). After corrections have been made for the idiosyncrasies of individual seismographs and stations, the magnitudes determined for a single earthquake in the Southern California Region usually show a range of not more than one-half unit on the scale. The range of magnitudes obtained for distant shocks may be somewhat larger. In routine reports the average magnitude, as determined from all available instruments, is given to the nearest one-half unit.

Under especially favorable conditions, earthquakes of magnitudes 1-1/2 have been reported felt near the epicenter; shocks of magnitude 3 are usually felt; those of magnitude 4-1/2 are capable of causing slight damage near the epicenter; while major earthquakes, capable of causing extensive damage, range from magnitude 7 to magnitude 8-1/2. There is no good evidence that any historical earthquake has had a magnitude much over 8-1/2.

The materials used include (a) a list [7] of all "normal" earthquakes of magnitude 7-3/4 and over, for the years 1904-39, (b) a list [7] of all "normal" earthquakes of magnitude 7 and over from January, 1926, through March, 1934, (c) a list of the earthquakes in a region of about 100,000 square miles, including most of southern California and part of Lower California, from January, 1934, through September, 1942, and (d) a selection from (c) of the earthquakes in a region of about

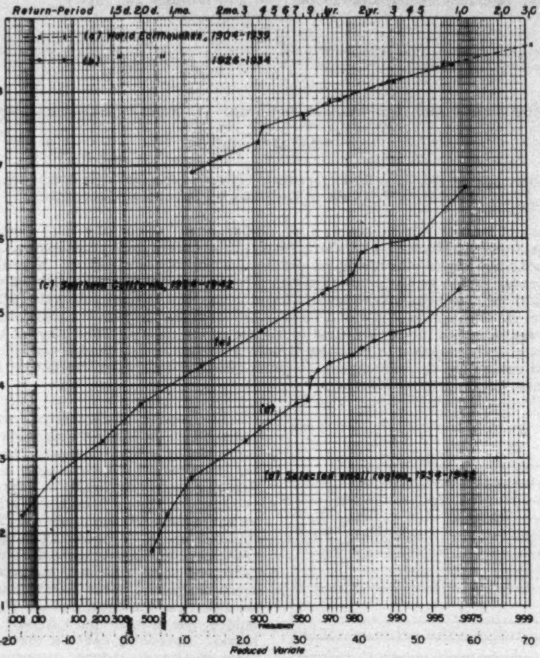


Fig. 2--Observed distribution of magnitudes of great earthquakes and Gumbel's theory of largest values

1300 square miles, east of Los Angeles. Lists (c) and (d) have been excerpted by the author from the "Local report" of the Seismological Laboratory in Pasadena.

Table 1 (parts a, b, c, and d) shows the reduction [8] of the data from the corresponding lists to the variable $F(\bar{x}_m)$ plotted on GUMBEL'S probability-paper in Figure 2.

It will be seen from Figure 2 that all the points plotted for the earthquakes of the entire world can be represented fairly well by a straight line. The same is true for the plotted points for each smaller region separately, indicating that in each case the observed distribution of the magnitudes of the largest earthquakes is in good agreement with the theory of largest values even when so short a time-interval as ten days is used as a unit.

References

[1] E. J. GUMBEL, Statistical control-curves for flood-discharges, Trans. Amer. Geophys. Union, pp. 489-509, 1942.

[2] E. J. GUMBEL, On the plotting of flood-discharges, Trans. Amer. Geophys. Union, pp. 699-716, 1943.

Table 1--Large earthquakes

M	Upper class-limit	No.	m for upper class-limit	$F(\tilde{x}_m)$
(a) Very large earthquakes of the world, 1904-42				
7 1/2	7.62	19	1242	.9576
7 3/4	7.87	19	1261	.9722
8	8.12	24	1285	.9908
8 1/4	8.37	7	1292	.9961
8 1/2	8.62	4	1296	.9992
(b) Large earthquakes of the world, 1926-34				
6.8	6.9		220	.738
7.0	7.1	26	246	.825
7.2	7.3	25	271	.909
7.4	7.5	10	281	.913
7.6	7.68	4	285	.956
7 3/4	7.87	6	291	.9765
8	8.12	4	295	.9899
8 1/4	8.37	2	297	.9967
(c) Earthquakes of southern California, 1934-42				
2	2.25	1	1	.0026
2 1/2	2.75	9	10	.031
3	3.25	61	71	.224
3 1/2	3.75	84	145	.459
4	4.25	96	241	.763
4 1/2	4.75	47	288	.911
5	5.25	18	306	.968
5.3		1	307	.971
(c) Concluded				
5.4		2	309	.978
5.5		1	310	.981
5.8		1	311	.984
5.9		1	312	.9873
6.0		2	314	.9936
6.7		1	315	.9968
(d) Earthquakes of small region in southern California, 1934-42				
1 1/2	1.75		166	.525
2	2.25	23	189	.598
2 1/2	2.75	41	230	.728
3	3.25	49	279	.883
3 1/2	3.75	21	300	.950
3.8		3	303	.959
4.1		1	304	.962
4.2		1	305	.965
4.3		2	307	.972
4.4		3	310	.981
4.5		1	311	.984
4.6		1	312	.987
4.7		1	313	.990
4.8		1	314	.994
5.3		1	315	.997

[3] B. GUTENBERG and C. F. RICHTER, Recent results of earthquake study in southern California, Trans. Amer. Geophys. Union, pp. 95-96, 1943.

[4] C. F. RICHTER, An instrumental earthquake magnitude scale, Bull. Seis. Soc. Amer., v. 25, pp. 1-32, 1935.

[5] B. GUTENBERG and C. F. RICHTER, On seismic waves (3d paper), Gerlands Beitr. Geophysik, v. 47, pp. 73-131, 1936.

[6] B. GUTENBERG and C. F. RICHTER, Earthquake magnitude, intensity, energy, and acceleration, Bull. Seis. Soc. Amer., v. 32, pp. 163-191, 1942.

[7] B. GUTENBERG and C. F. RICHTER, Seismicity of the Earth, Geol. Soc. Amer., Special Papers, No. 34, pp. 1-131, 1941.

[8] E. J. GUMBEL, Simplified plotting of statistical observations, Trans. Amer. Geophys. Union, pp. 69-82 , v. 26, 1945.

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(Manuscript received July 7, 1944; open
for discussion until January 1, 1946)

NOTES AND PERSONALIA

PERSONALIA

(See also pp. 11, 12, 27, 36, 82, and 128)

Albert H. Horton, for 42 years with the United States Geological Survey, died in Washington, D. C., March 4, 1945. He was born near Fairview, Butler County, Pennsylvania, on July 24, 1875. After receiving his degree in Civil Engineering at Cornell University in 1898, he was with the United States Deep Waterway Survey during 1898-99. From 1899-1903 he was Recorder and Junior Engineer engaged in river-surveys and measurements of flow of St. Clair and St. Lawrence rivers. From 1903 to 1905 he worked as Assistant Engineer and Engineer in preliminary investigations of the Shoshone and Utah Lake projects of the United States Reclamation Service. Since 1905 he has been Hydraulic Engineer and District Engineer with the Water Resources Branch, United States Geological Survey, and at the time of his death was Chief of the Division of Power Resources. He is the co-author of several Water-Supply papers for the United States Geological Survey.

Robert E. Horton died at his home near Voorheesville, New York, April 22, 1945. He was born at Parma, Michigan, May 18, 1875, and educated at Albion College where he received the degree of Bachelor of Science in 1897, and the honorary degree of Doctor of Science in 1932. From 1897 to 1911 he worked successively with the United States Deep Waterways Commission, United States Geological Survey, and United States Hydraulic Survey, following which period he entered consulting practice which he actively followed until his death. His consulting work included litigation involving intricate hydrometeorological problems, important assignments in State and Federal engineering projects, and board and committee leadership in basic research programs. Insatiable curiosity, careful observation, insistence on fundamental measurements, and rigorous interpretation of facts were inherent features of Horton's fertile mind. He enjoyed a keen sense of humor which was highly valued by his many friends.

Though Horton was primarily a pioneer hydrologist, his career was characterized by remarkable versatility. He made important contributions to hydrology, hydraulics, meteorology, forestry, hydroelectric power, phenology, climatology, water-law, physiography, and other fields. The science of geophysics has suffered a great loss in his passing. Horton's writings, numbering more than 150 in scientific magazines, in addition to a number of technical books, have greatly influenced current concepts of every phase of hydrology. An adequate biography of this scientist would nearly be an account of the development of modern hydrology.

Rudolph G. Kasel, Chief of the Division of Surface Water of the United States Geological Survey, died in Washington, D. C., June 14, 1945. He was born October 15, 1899, at Saint Louis, Missouri, served in the Navy in World War I, and graduated in 1923 from the School of Mines and Metallurgy of the University of Missouri. Kasel joined the United States Geological Survey in 1924 and served in the field in Arizona, Ohio, Idaho, British Columbia, and Montana, as District Engineer in Iowa, and since 1941 as Chief of the Division of Surface Water. As administrator of that Division Kasel contributed in great measure to the extension and continuity of the Survey's country-wide stream-gaging program.

Carl A. Ludy, Observer-in-Charge since 1944 of the Sitka Magnetic Observatory of the United States Coast and Geodetic Survey drowned near Sitka, Alaska, March 13, 1945. The deceased had been with the Survey since 1941, and had served as Observer-in-Charge at the San Juan Magnetic Observatory prior to his assignment at Sitka. He was born at Sitka where his father, Albert K. Ludy, had previously been Observer-in-Charge. His father had been with the Survey since 1921, having served also as Observer-in-Charge at the Tucson and Cheltenham magnetic observatories and as Chief of the Section of Geomagnetism from 1942 to 1944.

Thomas Riggs, Jr. died in Washington, D. C., January 16, 1945, after a lingering illness. He was born October 17, 1873, at Ilchester, Maryland. From 1903 to 1913 he was Surveyor and Engineer on the United States and Alaska Boundary Commission, from 1914 to 1917, a member of the Alaska Engineering Mission, and from 1918 to 1921, Governor of Alaska. Later he was Commissioner, Canadian-United States Boundary.

Napier Shaw, distinguished British meteorologist, died on March 23, 1945, at the age of 91. He was educated at Cambridge and Berlin, and was Director of the British Meteorological Office from 1905 to 1920. Later he occupied the Chair of Meteorology at the Royal College of Science. He was author and co-author of a number of outstanding works in meteorology.

Luther Creath Smith, Jr. was killed in an airplane crash near Rural Retreat, Virginia, on February 23, 1945. He was born March 8, 1918, at Taylor, Texas, and received his baccalaureate degree at the University of Houston. Smith was engaged in radio research and problems having to do with the construction and operation of broadcasting facilities.

Bruno S. Ulak, who was earlier reported as a prisoner of the Japanese, has since been reported as killed in action.

Vladimir Ivonovich Vernodsky, born March 12, 1863, a leading minerologist and geochemist in U. S. S. R., died January 6, 1945.

Transactions, American Geophysical Union Volume 26, Part I August, 1945

A THREE-COMPONENT PORTABLE SEISMOGRAPH FOR THE MEASUREMENT OF VIBRATIONS

L. Don Leet

General features--This instrument was designed and constructed primarily for the registration of vibrations from dynamite blasts, traffic, machinery, and general industrial sources. For vibrations of a frequency of three cycles per second or more, it gives a record directly proportional to displacement. With a magnification factor of 25 over this range, it gives clear, full registration from about 0.0005 to 0.035 inch. The maximum on-scale displacement which can be recorded usefully on any one of the components is 0.080 inch. Over a period of 15 years, experiments have shown that these constants are best adapted to the service for which this was designed.

The outside dimensions of the carrying case are 12 by 14 by 19-1/4 inches. There is a single handle on top for carrying by one person, or there are two on the sides for carrying by two people. The assembly weighs 65 pounds.

It is designed for 110-volt, 60-cycle operation, but the power-requirements are low enough to be met easily by a 100-watt converter if desired.

Details of construction--A cut-away perspective view of the interior of the seismograph is shown in Figure 1. It is basically a mechanical-optical system, magnetically damped. The inertia-elements are suspended by flat springs and have an undamped period of one second. On the vertical, these are supplemented by a stabilizing-coil spring. The horizontal components are at right-angles to each other.

In Figure 1, one of the horizontal components is shown in detail. The inertia-element is a cylindrical mass of brass. Above and below it are plugs, which close in on the cylinder and lock it for transportation, actuated by a knob on the top panel. Attached to the mass is a copper-vane which swings between the extended poles of an Alnico magnet, for damping. Also attached to the mass is an arm which extends forward to support the mirror for that component in a plane common to mirrors for the other components.

Light from the main housing on the top panel is supplied by a single-filament galvanometer bulb. The beam of light travels directly to a condensing lens just above three fixed mirrors. The concave mirror on the horizontal component shown in detail receives from its fixed mirror a rectangular patch of converging light with the long axis vertical. It returns an upright image of the lamp-filament to the face of the outer of two long plane mirrors. From there it goes to the inner long mirror, and so on by 11 reflections to a cylindrical lens which brings it down to a point and transmits it on to the surface of the photographic paper for registration. The eleventh reflection is from a small mirror which can be adjusted about a horizontal axis, through manipulation of a knob on the top panel, to aim the beam directly at the axis of the cylindrical lens.

The path of the light-beam for the vertical component is slightly different owing to the fact that the moving mirror on that component travels at right-angles to the horizontal components, and without some correction its light would move up and down on the large plane mirrors instead of from side to side, as it must to record properly at the camera. To take care of this, two prisms are interposed in the light-path of the vertical component. Neither prism is shown in Figure 1. The first intercepts the light on the way from the first small fixed mirror to the mirror of the inertia-element, and rotates the rectangle of light through 90°. The second prism is interposed between this point and the large front mirror. It returns the filament-image to a vertical position and causes it to move from side to side as the inertia-element mirror moves back and forth. From there on, the history is the same as that of the light-beams of the horizontal components.

Behind the cylindrical lens in the last step of the light-beam paths, there is a half-silvered mirror inclined at 45°. This picks off some of the light from each spot and throws it onto a frosted-glass plate in the top panel, where it can be observed visually during adjustment and operation.

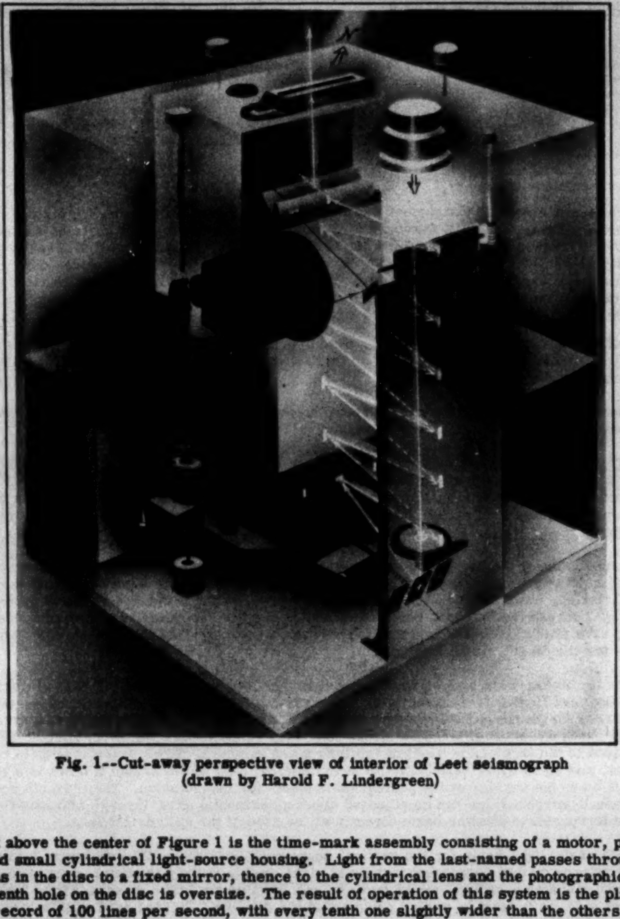

Fig. 1--Cut-away perspective view of interior of Leet seismograph (drawn by Harold F. Lindergreen)

Just above the center of Figure 1 is the time-mark assembly consisting of a motor, perforated disc, and small cylindrical light-source housing. Light from the last-named passes through perforations in the disc to a fixed mirror, thence to the cylindrical lens and the photographic paper. Every tenth hole on the disc is oversize. The result of operation of this system is the placement on the record of 100 lines per second, with every tenth one slightly wider than the others, to facilitate counting.

The camera is a separate unit. It holds an 85-foot roll of 70-mm wide bromide paper prepared for daylight loading. Figure 2 shows it with panel-cover open for removal of the camera. A pin in this cover holds the shutter open when it is in place, and allows the shutter to close when the cover is opened. Figure 3 shows the camera removed and opened for loading. The small disc on top of the camera is a footage-indicator. In Figure 1, just to the left of the time-mark assembly, can be seen the housing for the motor which drives the paper-feed in the camera, with the coupling-unit disengaged to show its details. The paper speed is approximately four inches per second.

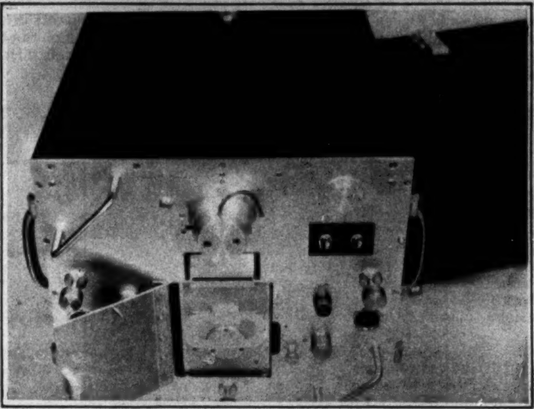

Fig. 2--Cover in top panel opened for removal of camera

Operation--The first step in operation is to level the instrument. Three levelling-screws are provided for this, operated from knobs on the top panel. A rough indication of level is obtained from a bubble on the top panel. Each inertia-element is then unclamped by rotation of the clamping-knobs on the top panel. When the light switch is turned on, a light-spot for each component should appear on the viewing screen. Final level is obtained by adjusting until the horizontal-component light-spots are in their proper positions, indicated by lines inscribed on the viewing-screen. The vertical-component light-spot is positioned by a small adjusting-screw which extends through the outside case, near the bottom. The seismograph is then ready for the taking of a record.

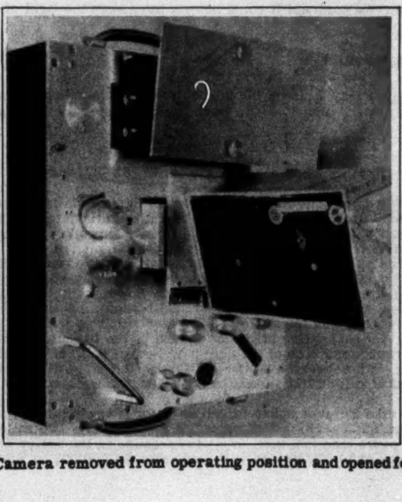

Fig. 3--Camera removed from operating position and opened for loading

The camera can be started by a switch on the top panel, or by a remote-control switch at the end of a cable, as shown in Figure 4. The motor of the camera will not operate unless the camera is in place and the knob which locks the camera panel-cover in closed position has been turned. This eliminates the embarrassing situation of standing blithely with all wheels turning, but no camera to take the record.

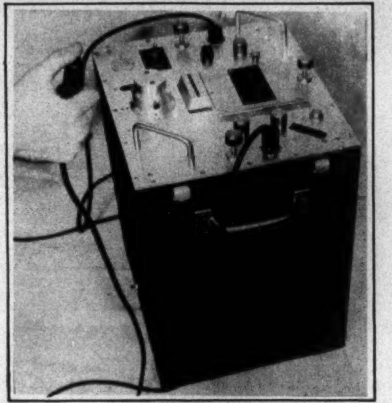

Fig. 4--Leet seismograph in operating position, with remote control-switch for starting and stopping

Acknowledgments--The LEET three-component seismograph was constructed with funds assigned by the Milton Fund of Harvard University, supplemented by gifts of friends of the Harvard Seismograph Station. It was designed for production and built by Laboratory Associates, an instrument-making firm of Belmont, Massachusetts, without whose personal interest far beyond the requirements of a commercial contract it could not yet have seen the light of day.

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NOTES AND PERSONALIA

NOTES (See also pp. 11, 12, 27, 32, 82, and 128)

Earthquake-resisting dam--The Autisha Dam on the Santa Eulalia River, now under construction some 50 miles from Lima, Peru, is unique in that it is articulated for the purpose of withstanding earthquake shocks. The channel in which the river flows is apparently of seismic origin. It is a chasm only 18 to 65 feet wide and 500 feet deep for a length of about 1,300 feet. The dam is being built on a concrete foundation that extends about 55 feet down to bedrock and about 35 feet above the normal water-surface. The dam is being built butterfly-shape in plan with the wing-sections separated by a space six inches wide closed by a length of concrete-filled iron pipe ten inches in diameter which will rest against two vertical I-beams set in the face of the dam at the inner ends of the wing-walls. The pressure of the water will hold the pipe against the opening end and thus effect closure, yet permitting slight movement of the two main portions of the superstructure. Near the downstream face of the dam a V-shaped strip of copper is provided to assure water-tight closure. A shaft between the pipe and the copper strip will serve to collect any water that passes the pipe and also to effect access to the inspection gallery.

The structure will rise 256 feet above the river-bed. If needs justify, it will later be raised 72 feet to impound about 7,300 acre-feet of water. A tunnel nearly two miles long will convey the water, under a head of more than 900 feet, to a power-house in the valley below. The completed plant will have a capacity of 30,000 kw and will cost from $5,000,000 to $6,000,000, including relocation of highways.

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SOME PROBLEMS ASSOCIATED WITH THE STABILITY OF THE WESTERLIES

Philip F. Clapp

I. Introduction

This study was designed to investigate the deepening and filling of waves in the Westerlies as revealed by five-day mean charts of the pressure-distribution at upper levels. On such charts frontal discontinuities are of little significance. Furthermore, the wave-lengths of the waves found on these charts are in general much longer than those of the usual cyclone-wave. Therefore, the study has been confined to the general theory of the stability of the Westerlies, where physical properties change continuously from place to place, rather than to the classical wave-theory of cyclones, where physical properties change in a discontinuous fashion at frontal boundaries.

The first study of the stability of the Westerlies was made by H. VON HELMHOLZ in 1888 [see 1 of "References" at end of paper]. More recent studies are those of MOLLER [2], ERTEL [3,4], HÖILAND [5], and J. BJERKNES and HOLMBOE [6]. The present study is based on an analogy between the problem of the stability of the Westerlies and the problem of vertical stability. An attempt is made to apply the results of recent studies of stability in relation to cloud-formation to the problem of the stability of the Westerlies (horizontal stability). It must be emphasized that the recognition of this analogy is by no means new, but has been discussed by several writers. It is hoped, however, that this attempt to carry out the analogy to its logical completion will throw some new light on the problem of horizontal stability.

II. The parcel-method

The general model of the circulation which will be used in this study is shown in Figure 1.

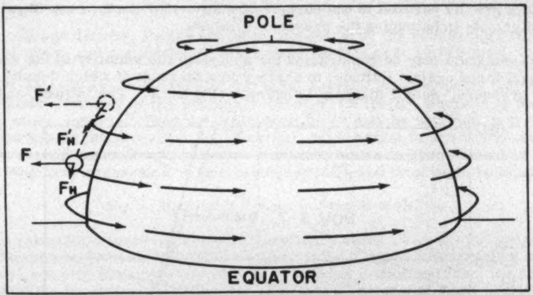

Fig. 1--Schematic model of general circulation

It is assumed that the atmosphere is an incompressible fluid whose absolute motion in space is a west-to-east rotation around the axis of the Earth. The density and speed of the fluid particles are assumed to be constant around any circular ring parallel to the circles of latitude. Such a ring of particles is called a "vortex-ring". The speed and density may, however, vary from one ring to the next. Such a circulation model is called the "baroclinic polar vortex". In Figure 1 is shown several vortex-rings, each of which is represented by a set of arrows whose length is proportional to the wind-speed. The vortex-rings are indicated at one level only. It must be emphasized that throughout this study the Earth is assumed to be spherical.

The stability of the polar vortex is studied by applying some kind of a disturbance, or perturbation, to the existing circulation and inquiring whether or not there will be acceleration in the direction of the perturbation, in which case the Westerlies are unstable. Various types of perturbations have been assumed by different writers. For the time being one type will be considered here, namely, that in which a parcel of air is forced to move northward parallel to the surface of the Earth. This is indicated in Figure 1, where the initial position of the parcel is indicated by the solid circle located to the left of the diagram on the second vortex-ring from the equator. The final position of this parcel is indicated by the dotted circle. The centrifugal force acting on this parcel, as it rotates around the Earth, will point outward at right-angles to the Earth's axis. This is indicated in Figure 1 by the arrow F. This centrifugal force will have a component parallel to the Earth's surface and toward the equator (F_H) which will have a magnitude

$$F_H = F \sin \theta \quad \text{(1)}$$

where θ is the latitude of the point in question.

Now it is clear that if we force this parcel to move northward its radius of rotation will decrease and, because of the conservation of angular momentum, its speed and therefore its centrifugal force will increase. The conditions under which such a perturbation will be stable or unstable may be stated very simply in the following way: If after being displaced, the parcel finds itself in a region where its centrifugal force is less than that of its surroundings, it will continue to move toward the pole, and therefore instability exists. On the other hand, if it finds itself in a region where its centrifugal force is greater than that of its surroundings, it will sink back toward its original position, and therefore stability exists. The criteria for stability may be expressed mathematically as in Equation (2).

$$\frac{\partial F_H}{\partial y} - \frac{dF_H}{dy} \begin{matrix} > \\ = \\ < \end{matrix} 0 \quad \left.\begin{matrix} \text{unstable} \\ \text{neutral} \\ \text{stable} \end{matrix}\right\} \quad \text{(2)}$$

where the positive y-axis points toward the north. ($\partial F_H/\partial y$) is then the local rate of variation of the centrifugal force in the environment of the parcel and (dF_H/dy) is the individual rate of change of the centrifugal force of the parcel as it is displaced. Equation (2) states, for example, that if the rate of change of the centrifugal force in the environment is greater than that of the air-parcel, then instability will exist. The analogy between the above criteria and the criteria for vertical stability is striking, since it is only necessary to substitute centrifugal force for density. The theoretical proof of Equation (2) will not be given here. It is quite clear that since there can be no component of gravity parallel to the surface of a spherical Earth, centrifugal force must take the place of gravity in balancing the pressure-gradient.

An "energy"-diagram may be constructed for analyzing the stability of the Westerlies by plotting centrifugal force against latitude, in analogy to a diagram in which density is plotted against height or pressure. Such a diagram is shown in Figure 2. The latitude-scale has been

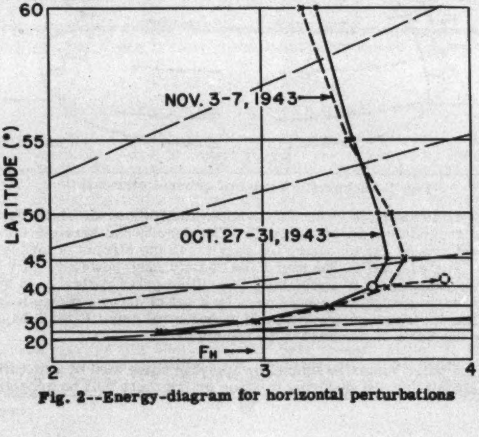

Fig. 2--Energy-diagram for horizontal perturbations chosen in such a way that lines on which an individual parcel will remain when displaced in accordance with the conservation of angular momentum, appear as straight lines. These are the slanting dashed lines in the diagram. They may be compared to dry adiabats. Areas on this diagram will be roughly proportional to the amount of energy involved in any displacement although this relationship will not be exact since the diagram is not a direct transformation of the PV-diagram. Centrifugal force is plotted in arbitrary units, and it is necessary to digress from the main subject in order to explain how it is obtained.

The 10,000-foot level has been chosen for studying the stability of the Westerlies. Since on 10,000-foot maps one never observes the simple zonal circulation-pattern illustrated in Figure 1, it is obvious that the variation of centrifugal force with latitude will be different for different longitudinal cross-sections. However, one may obtain the average centrifugal force around given latitude-circles in order to obtain a general picture of its variation with latitude. This has been done in this study by making use of five-day mean charts of the pressure-distribution at 10,000 feet. From these mean charts "pressure-profiles" are constructed by averaging the pressures between longitudes 180° and 0° along selected latitude-circles and then plotting on a graph average pressure against latitude. The use of these pressure-profiles in obtaining the centrifugal force will now be discussed.

The absolute centrifugal force of an air-parcel in a vortex-ring close to the Earth's surface is given by Equation (3).

$$F_H = (\rho v^2/R) \tan \theta \quad \ldots\ldots\ldots\ldots \quad (3)$$

where F_H is the horizontal component of the centrifugal force, ρ the density of the parcel, v its absolute west-to-east velocity, R the radius of the Earth, and θ the latitude.

In practice the density at a given latitude-circle may be obtained by averaging temperatures and pressures at 10,000 feet between longitudes 0° and 180°. However, since mean temperatures at 10,000 feet were not available at the time this study was undertaken, it was decided to use the average density between sea-level and 10,000 feet. It is assumed that this average density is proportional to that at 10,000 feet. The average density between sea-level and 10,000 feet is a function of the pressure-difference between these two levels, as shown by the hydrostatic Equation (4).

$$\bar{\rho} = (P_0 - P)/g\Delta z \quad \ldots\ldots\ldots\ldots \quad (4)$$

where $\bar{\rho}$ is the average density, P_0 the sea-level pressure, P the pressure at 10,000 feet, g the acceleration of gravity, and Δz the height-difference (in this case 10,000 feet).

The absolute velocity (v) is the sum of the zonal velocity relative to the Earth (U) and the velocity of the Earth's surface at the latitude in question ($V \cos \theta$), where V is the velocity of the Earth's surface at the equator. Thus the centrifugal force may be obtained in practical terms by substituting these values into Equation (3). However, all constant terms in the equation may be dropped since it is only necessary to consider a quantity which is proportional to the absolute centrifugal force. The final expression is then divided by 10^7, and thus we have Equation (5).

$$F_H = (P_0 - P)(U + V\cos\theta)^2 \tan\theta \times 10^{-7} \quad \ldots\ldots\ldots\ldots \quad (5)$$

where F_H is the centrifugal force expressed in arbitrary units, $(P_0 - P)$ the pressure-difference in millibars between sea-level and 10,000 feet taken from the pressure-profiles at latitude θ, U the relative zonal velocity in meters per second at latitude θ obtained from the 10,000-foot pressure-profile by taking the pressure-difference at points 5° north and south of the chosen latitude and then converting to the geostrophic wind. V is also expressed in meters per second (464 mps).

Values of centrifugal force computed in this way for two five-day mean periods, October 27 to 31, 1943, and November 3 to 7, 1943, are shown in Figure 2. It will be noted that both curves show a rather rapid increase in centrifugal force from latitude 25° to 45°, but from then on show an "inversion" or decrease of centrifugal force with latitude. The displacement of a parcel of air originally located at 40° north has been indicated for the period October 27 to 31, 1943. The initial position of the parcel, chosen in the steepest portion of the curve, is indicated by the solid circle. Its displacement along the lines representing conservation of angular momentum is indicated by the dotted arrow, and its final position by a dotted circle. It is seen at once that in its final position its centrifugal force is much greater than its surroundings, and therefore it will tend to sink back towards its original position. The two curves illustrated in Figure 2 have been chosen as representing extreme conditions of stability and instability as shown by the deepening or filling of troughs and ridges. Therefore it is necessary to conclude that the atmosphere is in general extremely stable for perturbations of the parcel-type. Thus, in following the analogy a result is obtained which is in agreement with the results of previous studies. The criteria for parcel-stability are the same as those originally proposed by VON HELMHOLZ, and it has been known for a long time that these criteria cannot account for the observed instability of the Westerlies. HAURWITZ [7] has recently shown that the atmosphere rotates approximately as a solid (constant angular velocity). It is easy to show that this would result in extreme stability for the parcel-type of perturbation.

Despite this apparent failure of the theory, it is nevertheless quite possible that variations in the "lapse-rate" of centrifugal force (change in centrifugal force with latitude) is critical in determining stability or instability. This may be compared to the problem of studying vertical stability by relating the observed stability (cloud-forms) to the lapse-rate of temperature. Thus in Figure 2, the period October 27 to 31, 1943, has been chosen because of extreme stability of the Westerlies as shown by the failure of troughs or ridges to intensify. On the other hand, the period November 3 to 7, 1943, has been chosen because of indications of extreme instability. It will be noted that at lower latitudes the lapse-rate of centrifugal force is greater in the unstable than the stable case, as should be expected. However, at higher latitudes this relationship is reversed. A preliminary study of the relationship between lapse-rate of centrifugal force at lower latitudes and deepening and filling of mean troughs in the eastern portion of the United States does not appear too promising.

It may be noted in passing that the computation of centrifugal force by means of Equation (5) is somewhat laborious. To simplify the computation use may be made of the fact that even under extreme conditions the percentage-variation in centrifugal force at a given latitude is very small. Thus departures of centrifugal force from a constant value may be obtained by first differentiating Equation (5) with respect to the factors leading to variation at a given latitude. Equation (6) thus follows.

$$dF_H = [(U + V\cos\theta)^2 \tan\theta \times 10^{-7}]\, d(P_0 - P) + 2[(P_0 - P)(U + V\cos\theta)\tan\theta \times 10^{-7}]\, dU \quad \ldots\ldots (6)$$

The constant value from which departures are measured has been chosen such that $(P_0 - P) = 300$ millibars and $U = 0$. Substituting these quantities into Equation (6), and expressing the geostrophic wind in terms of the equivalent pressure-difference per 10° of latitude, one obtains at 45° north

$$dF_H = [\,1.08\, d(P_0 - P) + 1.91\, \Delta P\,] \times 10^{-2} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

where $d(P_0 - P)$ is the departure of the pressure-difference between sea-level and 10,000 feet from 300 millibars and ΔP is the pressure-difference along the 10,000-foot pressure-profile between points 5° to the north and south of the chosen latitude.

The final expression for centrifugal force then becomes Equation (8).

$$F_H = F_{HO} + dF_H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where F_{HO} is a constant depending on latitude only.

It is found that computations made by this approximate formula contain errors of less than one per cent.

III. The slice-method

In the problem of horizontal stability, just as in the problem of vertical stability, it is necessary to recognize that the parcel-type of perturbation is physically impossible. Thus, it has been pointed out by J. BJERKNES, and later by PETTERSSEN, that the requirements of continuity demand that a given mass of rising air contained in a vertical slice of thickness δz be accompanied by a corresponding mass of sinking air in its environment such as in Equation (9)

$$M'V' = -MV \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where M' is the total mass of rising air contained in the slice δz, V' is its average upward velocity, and M and V are the corresponding quantities for the sinking air. An example of a perturbation of this type, where M' is assumed equal to M, is shown in Figure 3A. The problem in the case of vertical stability is to find out whether the difference in density at points e and f, following a perturbation, is such as to require some modification in the criteria for stability as given by the parcel-method. PETTERSSEN [8] in his treatment of the so-called "slice-method" showed that for dry adiabatically ascending air in a dry adiabatically descending environment the stability-criteria are still the same as for the parcel-method, although the amounts of energy involved are different. However, for moist adiabatically ascending air in a dry adiabatically descending environment the criteria are quite different, resulting in the requirement that the lapse-rate must be considerably steeper than the moist adiabatic for cloud-towers with finite width. In dealing with this problem PETTERSSEN developed what he called the "solenoid-producing term" which is a measure of the rate of production of isobaric-isosteric solenoids within the slice ABCD (Fig. 3A). The number of solenoids within the slice after the establishment of a perturbation depends on the density-difference between points e and f, and is therefore related to the stability. The particular theoretical approach used by PETTERSSEN was to obtain the solenoid-producing term by a transformation of the first law of thermodynamics. However, the same result can be obtained by an application of V. BJERKNES' circulation-theorem. In fact, this has been done by HÖILAND [5] and later by BEERS [9]. Application of the circulation-theorem leads to the conclusion that the number of solenoids within the slice ABCD after a short interval of time will be a measure of the net acceleration around the closed curve ABCD. This result is essentially the same as that obtained by PETTERSSEN with the exception that the particular distribution of the acceleration along the various sections of the curve is not specified. Thus, in order to relate the solenoid-producing term to the actual energy available for accelerating the cloud-towers it is necessary to assume that all the acceleration takes place along the branches of the curve AB and CD. If any of the energy is used to cause accelerations along BC or DA, leading to the production of turbulent eddies, the energy available for accelerating the cloud-towers will be diminished. In extreme cases, the eddies may completely nullify the effect of the solenoids. This restriction to the slice-method has also been discussed by BEERS [9]. The problem has been considered at some length here because it has a bearing on the application of the slice-method to the stability of the Westerlies.

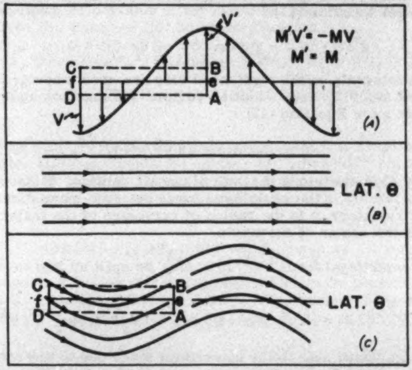

Fig. 3--(A) Sinusoidal north-south perturbation; (B) straight west-east stream-lines; (C) perturbed stream-line field

Figure 3A may be considered as representing a north-south perturbation applied to the westerly current illustrated in Figure 1. For this purpose it must be assumed that the surface of the Earth is a flat plane so that latitude-circles appear as straight lines. It is also necessary to stick to the original assumption that all motion takes place in horizontal planes. In that case the requirement of continuity demands that the mass of air moving toward the pole in unit-time across a given latitude-circle be equal to the mass moving toward the equator in the same horizontal plane. The result of such a perturbation when M' is equal to M is illustrated in Figure 3A. In order to describe completely the field of motion after applying this perturbation it is necessary to superimpose it onto the original straight west-to-east current shown in Figure 3B. The result is a sinusoidal wave-pattern, shown in Figure 3C. It is at once apparent that this type of perturbation is physically possible, since such wave-shaped stream-line patterns are observed on upper-level charts.

The stability of the Westerlies for such a perturbation presumably is still related to the difference between the centrifugal force of the northward-moving air and that in the southward-moving environment. Therefore, it is necessary to find out whether or not the difference in centrifugal force between points e and f (the inflection-points of the wave-pattern) will be such as to require some modification in the parcel-theory. The theoretical development involved will be outlined in the following paragraphs. Use is made of the circulation-theorem as in the development of the slice-method for vertical stability.

Equation (10) of motion is for absolute motion in vector-form.

$$\dot{\mathbb{W}} = -\nabla\varphi - \alpha\nabla P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where $\mathbb{W}$ is the absolute acceleration, $\nabla\varphi$ the so-called "gravity-potential", α the specific volume, and ∇p the pressure-gradient. Multiplying through by the density ρ and then integrating about the closed curve ABCD we get Equation (11).

$$\oint \rho \dot{\mathbb{W}} \cdot \delta\mathbf{r} = -\oint \rho \nabla\varphi \cdot \delta\mathbf{r} - \oint \nabla\rho \cdot \delta\mathbf{r} = 0 \quad \ldots\ldots\ldots\ldots\ldots (11)$$

It is clear that both the integrals on the right-hand side are zero since gravity has no component parallel to the Earth and since $\nabla\rho$ is a potential-vector. We may now split the absolute acceleration into two components as in Equation (12).

$$\dot{\mathbb{W}} = (dV/dt)\,\mathbb{T} + (V^2/r)\,\mathbb{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where (dV/dt) is the acceleration along the path of the air-motion, $\mathbb{T}$ is a unit-vector pointing in the direction of motion, (V^2/r) is the centrifugal force per unit-mass directed away from the center of curvature of the trajectory, r is the radius of curvature of the trajectory, and $\mathbb{N}$ is a unit-vector directed towards the center of curvature.

The total absolute centrifugal force $(V^2/r)\,\mathbb{N}$ may be split up into three components as in Equation (13).

$$(V^2/r)\,\mathbb{N} = (V_x{}^2/R\cos\theta)\,\mathbb{N}_n + (V_y{}^2/R)\,\mathbb{N}_r + (V^2/r_t)\,\mathbb{N}_t \quad \ldots\ldots (13)$$

The first term on the right-hand side is the centrifugal force due to the rotation of a particle of unit-mass about the axis of the Earth. This component is directed outward at right-angles to the axis of the Earth, in opposite direction to the unit-vector $\mathbb{N}_n$. In this term, V_x is the west-to-eas component of the particle-velocity, R the radius of the Earth, and θ the latitude. The second term on the right-hand side is the centrifugal force due to the rotation of the particle about the center of the Earth due to motion in a north-south direction. Here V_y is the south-to-north component of velocity, R the radius of the Earth, and $\mathbb{N}_R$ a unit-vector directed normal to the Earth's surface and toward the center of the Earth. The last term on the right-hand side is that portion of the centrifugal force due to the curvature of the trajectories in the plane of the Earth's surface. Here V is the total velocity of the particle, r_t the radius of curvature of the trajectory, and $\mathbb{N}_t$ a unit-vector parallel to the Earth's surface and directed toward the center of curvature of the trajectory.

Proof of the validity of Equation (13) will not be given here. It can be seen most easily by first considering a straight west-to-east flow as shown by Figure 3B. Since the motion is toward the east, the only centrifugal force acting on unit-mass is that given by the first term of Equation (13). Let us now apply a north-south perturbation V_y. We must then add to the existing centrifugal force a component given by the rotation of the particle in a south-to-north direction about the center of the Earth. This is the second term in Equation (13). If the perturbation (V_y) is not distributed uniformly along the latitude-circle, then some curvature is introduced in the plane of the Earth's surface (as shown by Fig. 3C) which adds a component to the total centrifugal force given by the last term in Equation (13). In general the total centrifugal force is the sum of these three components. Strictly speaking, the radius of curvature r_t must be measured on a projection, such as a Mercator projection, where the latitude-circles appear as straight lines.

Substituting Equations (12) and (13) into Equation (11) and rearranging, one obtains Equation (14)

$$\oint \rho[(dV/dt)\,\mathbb{T} + (V^2/r_t)\,\mathbb{N}_t] \cdot \delta\mathbf{r} = -\oint (PV_x{}^2/R\cos\theta)\,\mathbb{N}_n \cdot \oint\mathbf{r} - \oint(\rho V_y{}^2/R)\,\mathbb{N}_R \cdot \delta\mathbf{r} \quad \ldots\ldots (14)$$

The term in brackets on the left-hand side is seen to be the total acceleration parallel to the surface of the Earth, and which may be designated by the symbol $\mathbb{W}'$. The second integral on the right-hand side is zero, since $\mathbb{N}_R$ is always directed normal to the Earth's surface. Equation (14) may then be written as in Equation (15).

$$\oint \rho \mathbb{W}' \cdot \delta \mathbb{r} = -\oint (\rho V_x^2 / R \cos \theta) \, \mathbb{N}_n \cdot \delta \mathbb{r} \quad \ldots\ldots\ldots\ldots \quad (15)$$

Equation (15) is very similar to the corresponding equation for vertical motions. Evaluation of the integral on the right-hand side gives us the net acceleration per unit-volume around any closed curve parallel to the Earth's surface. It can be shown by further evaluating the term $\mathbb{N}_n \cdot \delta \mathbb{r}$ that this integral corresponds to the number of "solenoids" enclosed in the curve, where the solenoids are made up by the intersection of lines of constant centrifugal force and constant latitude.

To apply Equation (15) to the problem of the stability of the Westerlies one integrates around the closed curve ABCD in the direction of the perturbation. It is easy to see that the integral on the right-hand side drops out along the portions of the curve BC and DA, so that if the thickness of the slice (AB or CD) is equal to δy, Equation (15) becomes Equation (16).

$$\oint \rho \mathbb{W}' \delta \mathbb{r} = \left\{ [(\rho V_x^2 / R) \tan \theta]_f - [(\rho V_x^2 / R) \tan \theta]_e \right\} \delta y \quad \ldots\ldots\ldots\ldots \quad (16)$$

where the subscript e refers to the inflection-point east of the trough and f to the inflection-point west of the trough.

It is seen that the term $(\rho V_x^2 / R) \tan \theta$ is the centrifugal force of the Westerlies, which was designated as F_H. Equation (16) represents the number of "solenoids" contained in the slice ABCD. To get the "solenoid-producing term" it is necessary to differentiate Equation (16) with respect to time. Considering only stationary waves, and designating the net acceleration by the symbol A, one gets Equation (17).

$$(\partial A / \partial t) = [(\partial F_{Hf} / \partial t) - (\partial F_{He} / \partial t)] \, \delta y \quad \ldots\ldots\ldots\ldots \quad (17)$$

It is now desirable to evaluate Equation (17) at the moment when the perturbation is first applied. At the initial moment F_H is a function of y and t only. This results in the transformation in Equation (18).

$$(dF_H / dt) = (dF_H / dy) V_y = (\partial F_H / \partial y) V_y + (\partial F_H / \partial t) \quad \ldots\ldots\ldots\ldots \quad (18)$$

On recognizing that at the initial moment we have

$$(\partial F_{He} / \partial y) = (\partial F_{Hf} / \partial y), \; (dF_{He} / dy) = (dF_{Hf} / dy), \text{ and } M'V' = -MV,$$

and on rearranging Equation (18) and substituting it into Equation (17) one gets Equation (19).

$$(\partial A / \partial t) = V' \delta y [1 + (M'/M)][(\partial F_H / \partial y) - (dF_H / dy)] \quad \ldots\ldots\ldots\ldots \quad (19)$$

Equation (19) states that at the moment of application of the perturbation the rate of change of the net acceleration around the closed curve ABCD will depend for its sign on the term $[(\partial F_H / \partial y) - (dF_H / dy)]$. Thus it appears that the criteria for stability are the same as for the parcel-case. The problem may be compared to the case of air ascending dry adiabatically in a dry adiabatically descending environment. Just as in the case of the problem of vertical stability, it is necessary to recognize that the term A refers only to the net acceleration around the curve ABCD and does not specify just how the acceleration will be distributed in the various branches. Obviously a large number of possibilities present themselves. Only two possible solutions will be presented here. In one of these the acceleration will be assumed to be distributed evenly in the two branches of the curve AB and CD, with no acceleration along BC and DA. In the other solution, the acceleration will be assumed to be distributed in a uniform manner in all branches of the curve.

The first solution, in which the net acceleration is distributed uniformly in the two branches of the curve AB and CD, means that the "solenoid-producing term" may be related directly to the rate of increase or decrease of the south-to-north velocity components at the inflection-points, and therefore to the increase or decrease of the amplitude of the wave-disturbance. This type of perturbation may be compared to the type in which it is assumed that all the energy contained in the field of isobaric-isosteric solenoids is utilized in accelerating the cloud-towers. Because of the nature of the solenoid term [Eq. (19)] this type of perturbation is always stable. Furthermore, since there can be no accelerations along BC and DA the wave must develop symmetrically about an east-west axis, as shown in Figure 3C.

Next let us consider the case in which the net acceleration is distributed among all branches of the curve. The net acceleration is made up of two parts. One, along AB and CD, is related to the increase or decrease in amplitude of the wave-disturbance. The other, along BC and DA, may be assumed to be associated with the solenoid term. A type of wave-disturbance in which accelerations take place along BC and DA is shown in Figure 4. This is the type of perturbation discussed by J. BJERKNES and HOLMBOE [6] and which they call a perturbation of finite lateral extent. It will be seen that this type produces deceleration along BC and acceleration along DA. Therefore, this will act in the same direction as the solenoid-term and help damp out the wave-disturbance. Thus, wave-perturbations of the type discussed here will tend to be even more stable if of finite lateral extent. This result is in agreement with the conclusions of V. BJERKNES and others [10], who found that waves which they call "inertia waves", will obey the same criteria as in the case of the parcel-method.

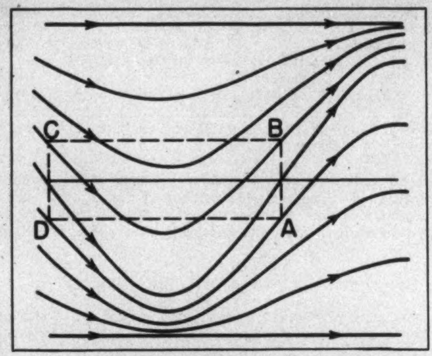

Fig. 4--Asymmetrically developing wave

IV. Conclusion

In conclusion, we may compare the above results with those obtained by J. BJERKNES and HOLMBOE [6], who found that long baroclinic waves may become unstable depending on the location of the so-called "level of non-divergence". The essential difference in these results lies in the assumptions regarding vertical motion. Since this study has been confined to the case of horizontal motion, no energy can be derived from circulation around the isobaric-isosteric solenoids. All energy must be derived from the existing kinetic energy of the Westerlies. We conclude, then, that only under extreme conditions will it be possible to transform the kinetic energy of the Westerlies into cyclonic vortices.

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AVERAGE AND EXTREME RANGE IN DEGREE-DAY UNITS IN THE UNITED STATES

Stephen S. Visher

A "degree-day" is one when the average temperature is 64°F. A day which has an average temperature of 54° is sometimes called "11-degree-days", and one with an average temperature of 0°, "65-degree-days". However, instead of calling a single zero-day 65-degree-days, here it is said to have 65 degree-day units.

J. B. KINCER, long chief of the Climate and Crop Weather Division of the United States Weather Bureau, made various useful studies of the regional contrasts in degree-day units in the United States during the few years before his recent retirement. Many data which were assembled under his direction, and organized by him, have recently been received from him by the present writer. A series of about 420 bar-graphs of the percentage-departure from normal of the season's total of degree-day units, 1898-1942, in ten sections of the United States have been studied, and yield disclosures of sufficient interest to warrant this paper. These bar-graphs, published in the Weekly Weather and Crop Bulletin for September 23, 1942, show notable fluctuation from year to year and for different parts of the country in the sectional averages of annual degree-day units. Table 1 shows the average and extreme upward and downward percentage-departures from normal in degree-day units as shown by the length of the bars. The upward departures mean sub-normal temperatures. Figures 1 and 2 are based on Table 1, and make more evident the regional contrasts in variability or range in degree-day units. Of course these maps are less satisfactory than comparable ones that could be made if data for variability were available for many stations, rather than for only the ten averages of many stations given in Table 1. It seems probable, however, that Figures 1 and 2 are fair approximations. They call attention to some interesting conditions, and will encourage someone to make detailed maps when additional data are available.

Table 1--Variation of degree-day units from normal, 1898-1942, by sections of United States, average percentage-departures above and below the 42-year normal

Section	Average upward departure	Average downward departure	Average range	Greatest upward departure	Greatest downward departure	Extreme range 42 years
	pct	pct	pct	pct	pct	pct
Northeast	5.0	5.0	10.0	12	14	26
E. North Central	7.5	4.3	11.8	15	18	33
Central North	7.3	5.0	12.3	16	14	30
Central Interior	6.3	6.0	12.3	18	14	32
Mountain-Plateau	7.0	6.0	13.0	20	26	46
Mid-Atlantic	6.0	7.3	13.3	18	18	36
Central South	10.1	12.0	22.1	31	23	54
South Atlantic	14.0	14.6	28.6	33	39	72
North Pacific	7.6	7.7	15.3	18	23	41
California	9.4	13.0	22.4	32	28	60

Figure 1 shows that the average range from year to year in degree-day units is least in the Northeast, where the average departures from the normal are only about ten per cent. The range is greatest in the Southeast, where it is more than 25 per cent. Of note also is the lesser latitudinal contrast on the Pacific Coast than on the Atlantic. The Great Lakes apparently help cause a lesser range in the Northeast than would occur if they were absent. Thus the presence of the Great Lakes may help to explain the greater latitudinal contrast on the Atlantic Coast than on the Pacific.

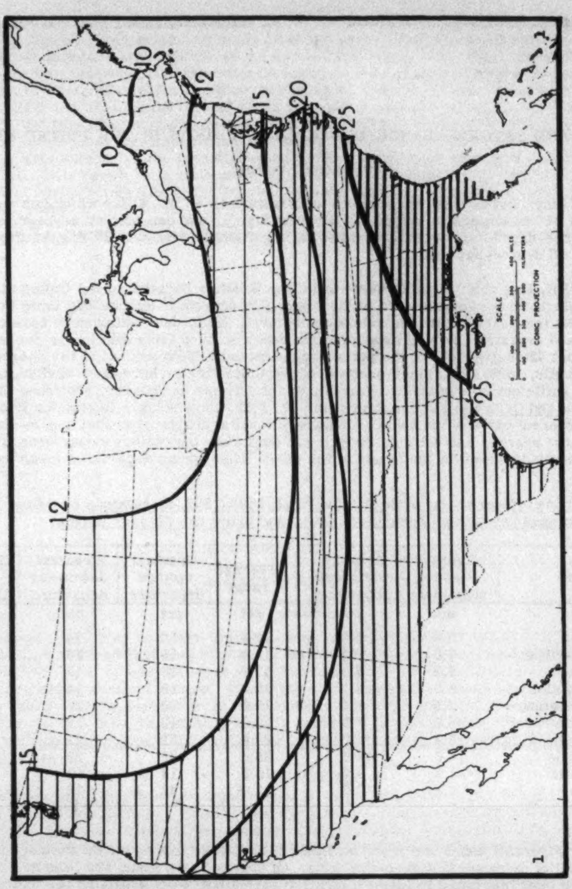

Fig. 1--Degree-day units, average variation from normal in per cent

Figure 2, of the extreme range, shows that the departure from normal during 1898-1942 was only about 25 per cent in the Northeast, and not much greater in most of the northern border of the country. It was more than twice as great near the southern margin of the country as near the northern, except on the Pacific Coast. A greater extreme range occurs near the Pacific Coast than in the central and northern interior, just as was true for the average range. This apparently reflects the variation from year to year in the amount of tempering effect of the Pacific Ocean which is carried inland by winds.

A third map, not published here, of the percentage of the years which have approximately the average number of degree-day units, may be mentioned. It reveals that in the northern sections of the country from 50 to 60 per cent of the years are within five per cent of normal. In the central-southern section, only one-third of the years is in this category, in California only 26 per cent, and

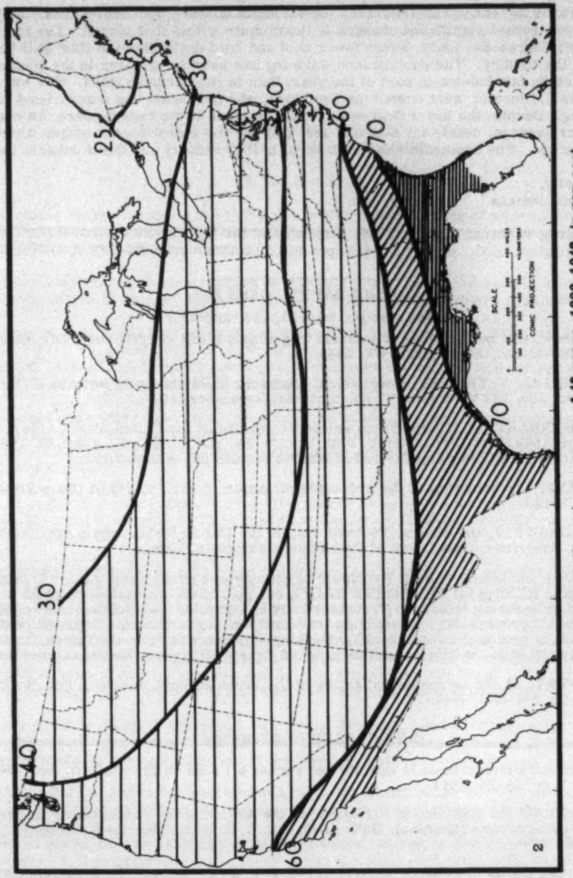

Fig. 2--Degree-day units, extreme range of 42 years, 1898-1942, in per cent

in the South Atlantic States only 17 per cent. Thus, in the Southeast about five-sixths of the years depart rather widely from average.

The fact that the coldest section of the country, the eastern Montana-North Dakota Region, where 10,000 degree-day units occur in an average year, is less variable from year to year in the number of the degree-day units than any other section, except the Northeast, is of interest. This indicates, despite the "blizzards" and other sharp changes in temperature, that region has relative uniformity year by year. By contrast, in the South, although the average season has little cold weather, some are much colder than normal and others remarkably mild. This greater unpredictability of cool-season temperatures in the South is a handicap of considerable economic and health significance. The financial loss to the producers of fruit and early vegetables caused by exceptionally cold weather is often great. The uncertainty as to what to expect is discouraging to progress.

The bar-graphs for each year 1898-1942 (centering in winter), upon which Table 1 and Figures 1 and 2 are based, reveal significant changes in the climate within that period. The last half of the period has fewer degree-day units, hence fewer cool and cold days, than the first half had in all ten sections of the country. The cool-season warming has been far greater in the southern third of the country, already far-too-warm part of the year, than in the northern third. The warming has been greatest in California; next comes the Southeast; the Northeast has experienced least cold-season warming. Despite the fewer degree-day units in most of the recent years, as compared with the 42-year average, nearly all sections have had one (or more) recent winter which was much colder than average. The Southeast has fared worst in this respect and the Northeast best.

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A STUDY OF NORTHERN HEMISPHERE PRESSURE-CENTER TRACKS

L. W. Sheridan

Many attempts have been made to arrive at a better understanding of atmospheric processes by a study of the movement of the migratory high- and low-pressure centers which follow more or less regular paths over the Earth's surface.

As early as 1884 charts were published by FINLEY [see 1 of "References" at end of paper], showing relative storm-frequency for quite a large portion of the Northern Hemisphere.

Another more comprehensive study appeared in 1893, based on work done under the direction of DUNWOODY [2]. This summarized observations over most of the Northern Hemisphere for the ten-year period 1878-87. It includes average storm-tracks for months and for seasons, and storm-frequency by 5°-squares for each month of the year.

Two valuable and widely used contributions to the study of types and movements of lows and highs were made by BOWIE and WEIGHTMAN [3,4]. The former pertains to lows and the latter to a similar study of anticyclones. The data used in these studies covered the United States and a small portion of Canada.

Source of material--In the present study the source of data was the ten-year series of Northern Hemisphere sea-level historical weather maps for the years 1929-38, recently published by the United States Weather Bureau.

The high- and low-pressure centers on these maps were tracked by plotting their successive positions at 24-hour intervals on a chart of the Northern Hemisphere and connecting these points with a smooth curve. Highs and lows were plotted on separate charts. Three charts were used for each month of highs and three for each month of lows, so that any one chart would not contain too much material. Adjacent charts have two days in common. For example, May 30 to June 10 appear on one chart, June 9-20 on the next, and June 19-30 on the third. Thus the 9th and 10th appear on both the first and second charts, the 19th and 20th on the second and third, and so on. In this way it is possible to follow the continuity from chart to chart with little difficulty.

Above each center on the track-chart was placed the date, and below the center the last two digits of the pressure, measured to the nearest millibar. The pressure used was the estimated central pressure and not necessarily that of the inner isobar.

The symbol used to locate the position of a high was identical for all centers, but the centers for lows were classified as to type of center according to eight different categories.

No value of pressure was assigned when there was no closed isobar or no closed circulation about the center. It was believed that in these cases it would be of little value to assign an arbitrary pressure to the system.

Data taken from these track-charts were used as the bases for the material presented in this report.

Preliminary investigations--One of the principal objects of the present study was to extract and summarize data taken from the track-charts, and to present them in such a manner that they would give the forecaster, when confronted with a specific problem in weather-analysis, a clue to the probability of future developments of weather. For this reason a considerable amount of preliminary work was done by way of considering various monthly and seasonal summaries before the final type of summarization was decided upon.

Tabulations of the frequency with which centers crossed given meridians in selected areas were made. The variation of central pressure with latitude along a given meridian was determined, and the average central pressure computed for each of various bands of latitude. The speed of movement over a 24-hour period was calculated and some averages obtained for limited areas. The time-interval between successive centers crossing a given meridian was also calculated and average intervals were obtained. Areas where storms first made an appearance on the track-charts were noted and these frequencies were summarized by 5°-squares. Areas of stagnation, where centers remained at least 24 hours in the same 5°-square, were tabulated as illustrated by Figure 1. The numbers in each 5°-square indicate the number of times a given center was observed in that square on successive days.

Several possible relationships were tested by the use of correlation-studies. In order to determine whether or not lows tended to accelerate after they began to fill, lag-correlations were computed between 24-hour pressure-changes at the center and the subsequent 24-hour speed. This was done over only limited areas. No correlations were found which were large enough to meet the level of significance of five per cent for this limited sample of data. However, the sign of the correlation-coefficients suggested a slight negative acceleration of the centers after filling.

To determine whether or not lows tended to move northward after filling, lag-correlations were computed between the 24-hour pressure change at the center and the northward or southward movement measured in degrees of latitude, during the subsequent 24-hour period. Of the 18 coefficients computed, five were large enough to meet the level of significance of five per cent. These coefficients indicated a northward movement of the centers after deepening.

Two more such correlation-studies completed this part of the preliminary investigations. This time the correlation-coefficients were computed between change of latitude and speed of movement and vice versa. A 24-hour lag was used in both directions. In the first instance, in which the change of speed was subsequent to the latitude-change, five of the 18 coefficients met the level of significance of five per cent. They indicated a positive acceleration subsequent to northward movement. In the last case, in which latitude-change was subsequent to change of speed, one significant value was obtained, which suggested that a southward movement followed positive acceleration.

An attempt was made to select typical weather-sequences by using the frequency-distributions of low centers by 5°-squares as a guide. This was done for the Northern Pacific Area as indicated in Figure 2. Lines of equal frequency were drawn and the paths of greatest frequency indicated by heavy black arrows. Figures 3 and 4 show two examples of centers which approximately followed the paths of greatest frequency; the heavy arrow in each Figure is merely a reproduction of part of those shown on Figure 2.

Due to the limited area covered by the data at the time this phase of the study was made, it seemed advisable to postpone further work along this line until adequate data become available.

Final charts--The final summarization consisted of the preparation of monthly charts based upon the ten-year period 1929-38.

To insure an objective evaluation of the data, it was decided to use only those data which referred to the pressure-centers as of the time of observation, and thus no interpolation of pressures or other data between successive 24-hour positions was used.

The central pressures of the lows and highs were tabulated from the track-charts by 5°-squares for the entire Northern Hemisphere. To date, summary charts have been compiled for specified areas only. Figures 5 to 9 illustrate the five types of charts which were prepared for each month of the year for each area. Figure 5 gives the total frequency of lows observed in each 5°-square at 13^h00^m Greenwich Mean Time for the ten Januarys 1929-38. Figure 6 is a similar chart for the highs.

Figures 7 and 8 are the frequency-distribution of the central pressures grouped into five-millibar classes.

Figure 9 gives the distribution of the number of lows per month observed in each 5°-square. For example, the graph in the square whose southwest corner is at 40° north and 25° west indicates that of the ten Januarys there were seven during which no center was observed in the square at 13^h00^m GMT, two when a single center was observed, and one when two centers were observed. This gives a total frequency of four centers during the ten Januarys and this frequency may be observed in the corresponding square on Figure 5.

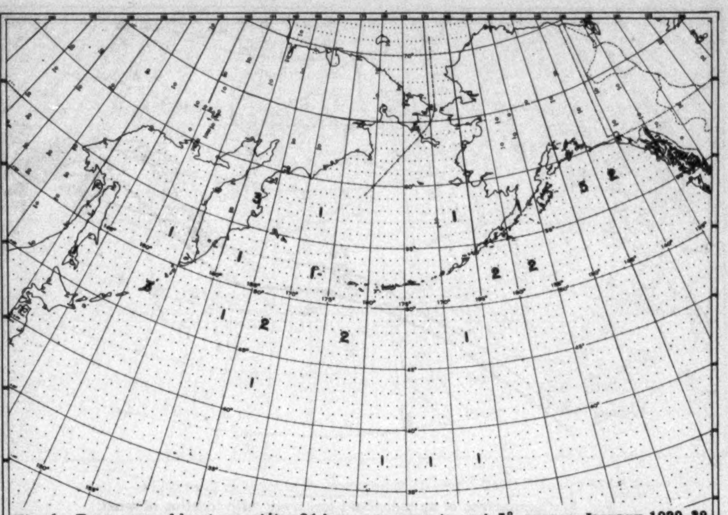

Fig. 1--Frequency of lows remaining 24 hours or more in each 5°-square, January 1929-38

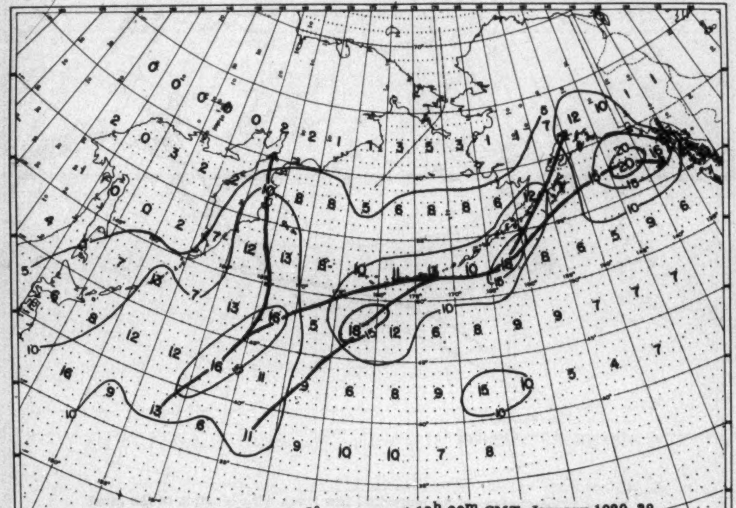

Fig. 2--Frequency of lows in 5°-squares at 13h 00m GMT, January 1929-38

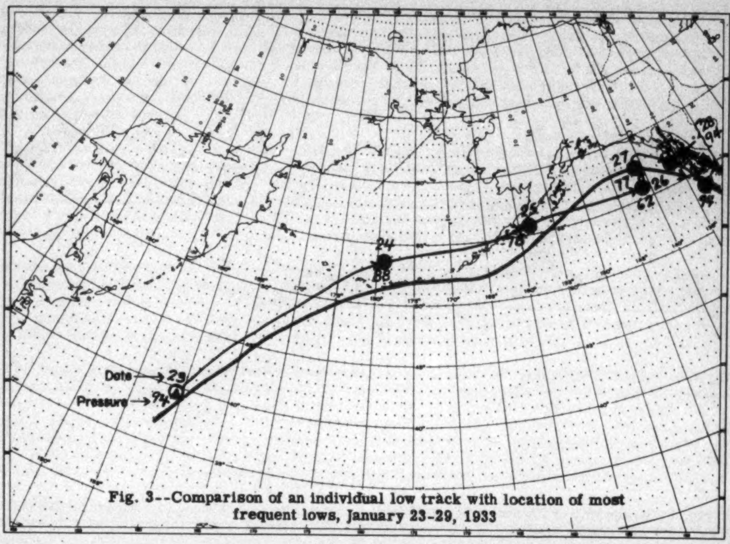
Date
Pressure
23
94
24
88
25
78
27
77
26
62
28
94
94

Fig. 3--Comparison of an individual low track with location of most frequent lows, January 23-29, 1933

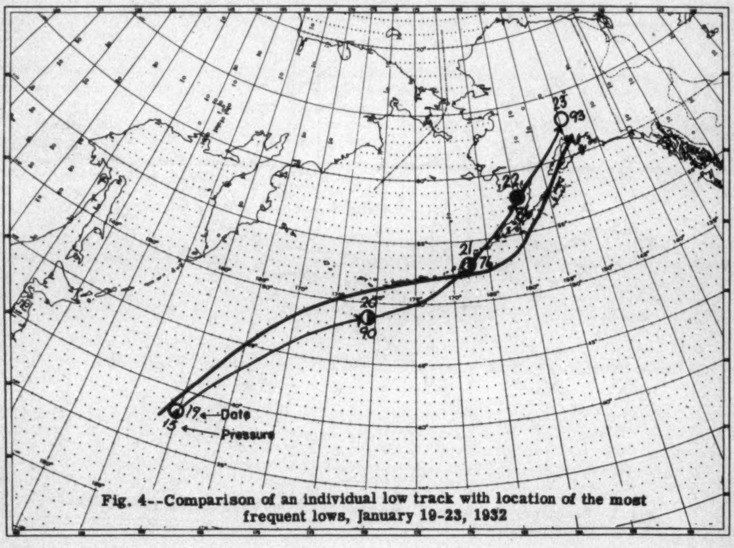
23
93
22
21
76
20
90
19
15
Date
Pressure

Fig. 4--Comparison of an individual low track with location of the most frequent lows, January 19-23, 1932

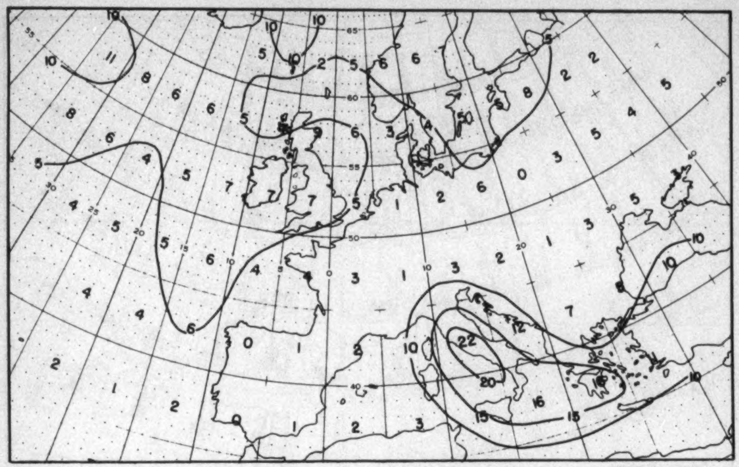
10
10
10
65
11
10
8
6
6
5
2
5
6
6
60
8
5
9
6
3
4
5
8
2
2
5
4
6
5
4
5
7
7
7
5
55
1
2
6
0
3
5
4
5
5
6
4
3
1
3
2
1
3
50
10
10
8
4
4
6
7
12
22
0
1
2
10
20
16
16
15
15
10
2
1
2
0
1
2
3
40

Fig. 5--Frequency of lows in 5°-squares at 13^h 00^m GMT, January 1929-38

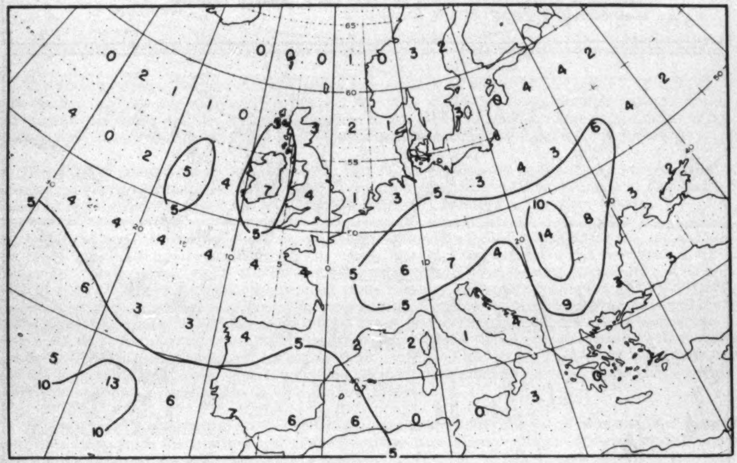
65
0
0
0
0
1
0
3
2
2
1
0
60
4
4
2
2
4
1
0
3
2
1
3
4
0
2
5
4
3
7
4
1
3
5
6
5
3
4
3
55
5
4
4
4
4
5
1
3
5
3
10
14
8
3
4
4
4
5
6
7
4
9
3
6
3
5
3
3
4
1
4
5
2
2
1
5
10
13
6
7
6
6
0
0
3
10
5
40

Fig. 6--Frequency of highs in 5°-squares at 13^h 00^m GMT, January 1929-38

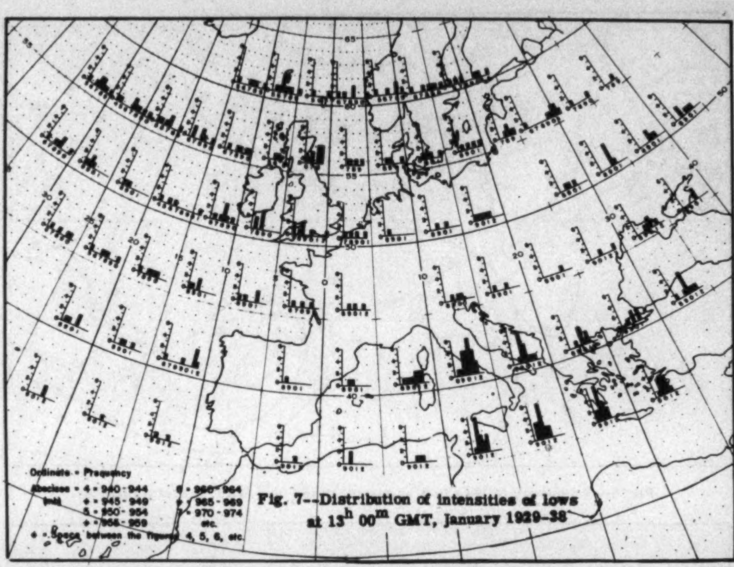
65
60
55
50
40
30
25
20
15
10
5
0
10
20
30
40
50
Ordinate = Frequency
Abscissa = 4 = 940 - 944
(mb) • = 945 - 949
5 = 950 - 954
• = 955 - 959
6 = 960 - 964
• = 965 - 969
7 = 970 - 974
etc.
• = Space between the figures 4, 5, 6, etc.

Fig. 7--Distribution of intensities of lows at 13^h 00^m GMT, January 1929-38

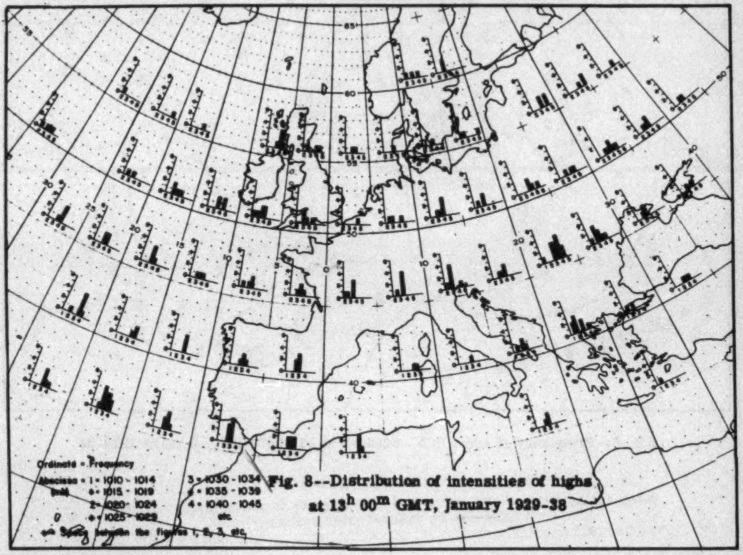
65
60
55
50
40
30
25
20
15
10
5
0
10
20
30
40
50
Ordinate = Frequency
Abscissa = 1 = 1010 - 1014
(mb) • = 1015 - 1019
2 = 1020 - 1024
• = 1025 - 1029
3 = 1030 - 1034
• = 1035 - 1039
4 = 1040 - 1045
etc.
• = Space between the figures 1, 2, 3, etc.

Fig. 8--Distribution of intensities of highs at 13^h 00^m GMT, January 1929-38

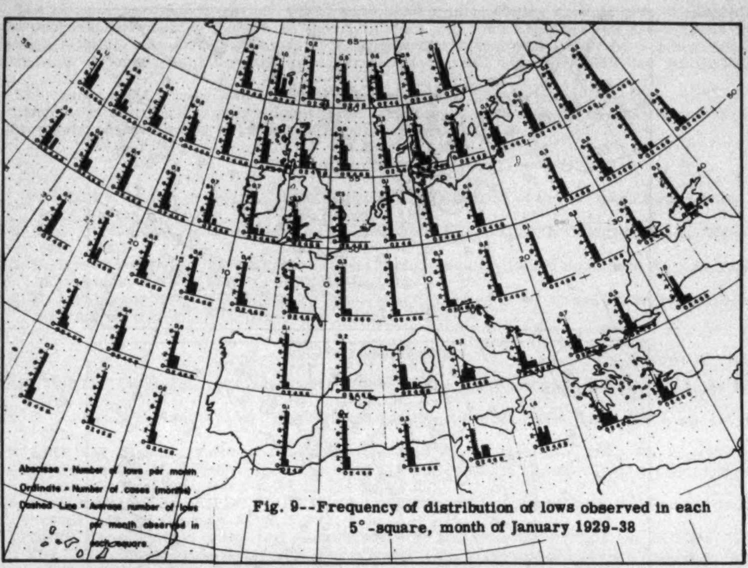
Abscissa = Number of lows per month.
Ordinate = Number of cases (months).
Dashed Line = Average number of lows per month observed in each square.
65
60
55
50
40
30
25
20
15
10
5
0

Fig. 9--Frequency of distribution of lows observed in each 5°-square, month of January 1929-38

The distribution of the intensities of these four centers is indicated in Figure 7. It may be seen that one of them had a central pressure in the 985- to 989-mb class, another appears in the 990- to 994-mb class, and the remaining two are in the 1005- to 1009-mb class. A similar relationship for centers of high pressure may be observed by comparing Figure 6 and Figure 8.

It should be pointed out in this connection that the centers on the track-charts for which no value of pressure was indicated (where there was not a closed circulation), cannot be included in charts of the type of Figures 7 and 8. They are, however, included in the other charts.

A comparison--A comparison of the frequencies found by DUNWOODY [2] for the years 1878-87 was made with the frequencies found for the years 1929-38. An example of the result is shown in Figure 10. The frequencies for the earlier period are those of the passage of migratory centers through each 5°-square, whereas the present study includes all centers observed at $13^{h}00^{m}$ GMT. A similarity in the patterns may be noted, such as high frequencies occurring over Italy and the eastern Mediterranean in both cases as well as along the northern and northwestern part of the area covered by the charts. Also, minimum frequencies occur in both periods over western Spain and in the square whose southwest corner is at 50° north and 20° east. This would seem to indicate that the frequencies observed over two sizable periods, separated by about 50 years, show little overall change in the distribution of high and low centers.

Summary and conclusions--Rather extensive preliminary investigations of methods of summarizing data taken from the track-charts of the Northern Hemisphere of high- and low-pressure centers for the ten-year period 1929-38 were made.

During these early investigations it was kept in mind that the final summaries should be of such a form that they might serve as a guide in forecasting weather. These preliminary studies included the testing of a number of relationships by computing simple linear correlation-coefficients but few were found to be significant.

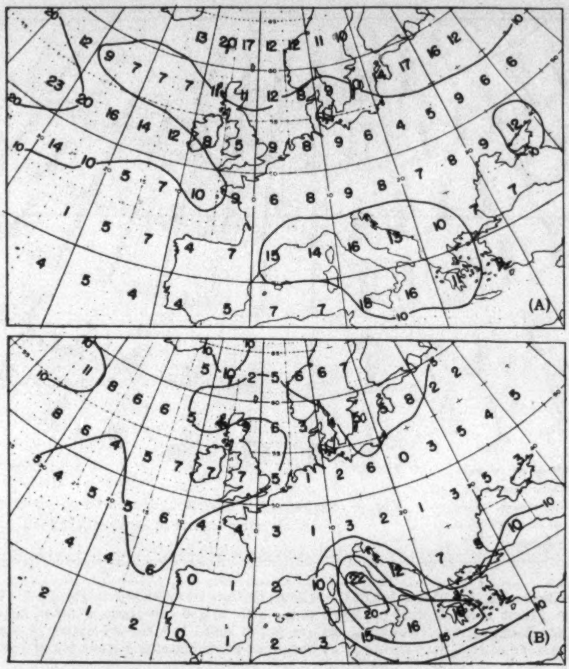

Fig. 10--Frequency of January lows: (A) Passage through each 5°-square, 1878-87; (B) in 5°-squares at $13^h\ 00^m$ GMT, 1929-38

After various preliminary tabulations of frequency, speed, etc., it was decided to prepare five charts for each month of the year. Each of these was identified by a number and a letter, the numbers 1 to 12 indicating the month, and the letters A to E indicating the type of chart as illustrated in Figures 5 to 9.

It seems evident from the magnitude of the frequencies observed over a ten-year period, that a longer record is desirable. It is also desirable to treat the hemisphere as a whole, rather than to confine such a study to the limited areas which war-time demands made necessary in the present case.

It might be well at this point to suggest some possible uses for such charts. In the first place they serve to give the forecaster some idea of what may be expected on the basis of past data. The limits of intensities and frequencies shown by such charts offer a guide in making a prognostic chart. For example, if the lowest pressure observed over a ten-year period in a given area is 950 mb, the knowledge of this fact would indicate that extreme caution should be used before placing a center lower or even as low on a prognostic chart.

Similarly the charts showing total frequency of centers indicate the frequency that may be expected in any given area.

The paths of maximum frequency, which were illustrated in Figure 2, might give valuable clues to the probable movement of centers, especially if more data were available and larger areas considered. A further and obviously necessary refinement for such a study would be to sub-divide the centers into various types, following a procedure similar to that used by BOWIE and WEIGHTMAN.

The charts might also be used in climatic investigations, to determine long-range trends in frequency or intensity-patterns, or to relate the variations in such patterns to other atmospheric or terrestrial phenomena, or to variations in solar activity.

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(Manuscript received May 16, 1945, for presentation at Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until January 1, 1946,)

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS (See also pp. 18, 68, 90, and 126)

STEPHEN S. VISHER: Climate of Indiana. Bloomington, Indiana Univ. Pub., Sci. Ser. No. 13, 511 pp., 492 figs., 81 tables, 1944.

Climatology naturally divides into two categories: (1) "Methods," including the climatological elements--their derivations and inter-relationships--statistical treatment of data--including the problems of curve-fitting, with general and inter-regional application--observational practices as affecting the validity and homogeneity of data, etc.; and (2) applied climatology for a specific area, preferably with special attention to anomalies, supplementary to the basic data, especially important to agriculture and valuable to many other industries in affording a "Weather Guide" based on the frequency of occurrence of significant phenomena. VISHER'S book relates primarily to division (2) as above. In addition to presenting basic climatological data for Indiana, mostly in graphic form, it features expectancies of significant and important weather -occurrences for different parts of the State. It constitutes the most complete climatological history extant for any State.

Recently ISAIAH BOWMAN very aptly declared that "facts more valuable than all the gold in the Klondike lie hidden in the climatological records of the Weather Bureau." VISHER has brought to light a wealth of these facts that have lain dormant for many years in the archives of the Indianapolis Weather Bureau and has given to them a status of utilization.

The first chapter contains a general summary of Indiana's climate, followed by discussions of the several climatic elements, profusely illustrated by maps and graphs with a minimum of tabular matter. Many of the illustrations have to do with variations from the standard normals which bring out graphically pertinent facts in anomalies and the "to be expected" (in the long run) frequencies of significant and important weather-occurrences. Such information is especially valuable in long-time agricultural planning and for many other industries. It is hoped that this pioneer work may encourage other climatologists to follow the lead for other States.

Supplementing the basic data are many auxiliary maps and graphs, among which the following deserve special mention: The lowest temperature of record in 80 per cent of the years, that is only one year in five has experienced lower temperatures than those given; the average annual number of cold days with sub-freezing daily normal temperature, moderately warm days with temperatures 50°-68°, and hot days with daily normals 75° or higher; dates of beginning and ending of summer, based on daily normal temperature of 68°; average depth of frost-penetration; number of days per decade with temperature continuously below 10°, 20°, and the lowest for the coldest month of the year in 20 per cent of the years (that is, in 80 per cent of the years the temperature did not go lower than those shown on the map). Several maps show various rainfall-intensities such as the percentage of years with three or more inches in three successive days. In many cases data, both temperature and precipitation, are given for pairs of successive months, supplementing the usual seasonal (three-month) maps. This device is used also in summaries of drought, such as rainfall-totals for the driest pair of months during the crop-growing season.

Several maps show maximum and minimum values of data that are exceeded in a relatively small percentage of the years, such as dry months for which the values given are exceeded for dryness in only 20 per cent of the years (that is, a drier month may be expected, on the average, only one year in five). An interesting map shows drought-frequency in terms of the sum of the percentage of normal rainfall for each of the three summer months (June-August) when each receives less than 1.5 inches. In addition, maps are included showing the average dates of planting and harvesting important crops and the temperature-relation to these dates in its annual march.

VISHER has not only extracted much "gold" from the Indiana records, but, as another feature of his book, has included a well-deserved "recognition of the services of the climatological observers of the Weather Bureau, whose unselfish devotion to their observational work, often for long periods of time, makes possible such valuable publications as here presented. These thousands of public-spirited men and women, instead of asking the all-too-frequent question 'what is there in it for me?', are content with the conscious satisfaction of a public service faithfully rendered to their communities, State, and Nation, not only for current utilization, but also a heritage to generations yet unborn." The records show that for Indiana 39 observers have served, past and present, for periods ranging from 20 to 60 years, and this State until very recently had the dean of the some 5,000 for the United States, ELWOOD KIRKWOOD, Mauzy, with a record of more than 60 years of service. KIRKWOOD passed away a few months ago.

In brief, the book is outstandingly complete in subject matter, and profusely illustrated, containing nearly 450 climatic maps for Indiana, in addition to many other forms of graphic presentations--the greatest number ever published for any State. Among the some 80 tables of climatic data, detailed weather-records for long periods of time are given for key Weather Bureau stations representing different areas of the State. Most of the maps could well have been in larger scale but this, in view of their great number, would have increased greatly the size of the volume. However, if this had been possible, it would have been well worth-while. VISHER truly has presented a challenge to climatologists of other States, a guide for future studies, and a model for publications of like character.

J. B. KINCER

Transactions, American Geophysical Union Volume 26, Part I August, 1945

INFILTRATION AND RUNOFF DURING THE SNOW-MELTING SEASON, WITH FOREST-COVER

Robert E. Horton

Synopsis--This paper presents a new method of analysis of rainfall- and runoff-data which permits surface-runoff and ground-water flow to be segregated and infiltration-capacity determined during stream-rises. The method is equally applicable to areas with and without snow-cover. The determination of infiltration-capacity during the snow-melting periods is, however, the most difficult problem and the method is here applied to this case, using data for areas in the Allegheny Experimental Forest, with varying degrees of forest-cover density. For these areas the rate of snow-melting per degree-day of temperature excess above 32° decreased as the cover-density increased.

During snow-melt, infiltration took place at rates governed by the rate of supply of rain and melt-water, averaging for the entire snow-melting period one-third to one-quarter of the infiltration-capacity of the soil. The infiltration-capacity under snow-cover with unfrozen soil was found to be about 0.05 inch per hour or 1.20 inches per day. There was no significant difference between infiltration-capacity of these areas with different forest-cover densities. Since the infiltration-capacity of these areas greatly exceeded the average rate of supply of melt-water during the melting-period, and the rate of supply of melt-water decreased as the forest-cover density increased, it appears that, under the conditions of the experiments, increased forest-cover may operate to materially reduce runoff-intensity during the snow-melting period. The opposite effect can, however, be brought about by the occurrence of a rain on ripe snow in the forest at a time when the snow-cover would have disappeared from an open area. On the other hand, snow-cover in forest may absorb a rain which would produce heavy runoff from decreased snow-cover or bare ground in the open, especially if the soil-surface in the open has frozen after the snow disappeared.

Data used--Data collected during the snow-melting period on four small drainage-basins in the Allegheny National Forest near Kane, Pennsylvania, in the spring of 1940, are shown in Figures 1, 2, 3, and 4. Data of rainfall, snow-cover, and runoff are from data collected by the United States Forest Service [see 1 of "References" at end of paper]. Lines showing maximum and minimum temperatures, gain or loss of ground-water storage, and ground-water flow have been added by the author.

The vegetal cover-conditions on these areas are described as follows (op. cit.):

Gilfoyle Run--"This area is relatively free of forest-cover and is representative of the logged and severely burned lands of northwestern Pennsylvania. In the valley and on the slopes are scattered clumps of beech, aspen, and black and fire cherry. The headwaters-areas above the slopes are fairly well stocked with sapling stands of northern hardwoods. Many of the understocked and open portions of the watershed are planted to red pine and spruce. Crown-closure of these plantations cannot be expected for another 10 or 15 years."

McKee Run--"McKee Run has been logged once for saw timber and recut for chemical wood. Approximately 30 per cent of the area appears to have been severely burned. The watershed is now almost completely covered with young stands composed chiefly of northern hardwood species of sprout origin. Scattered groups of aspen occur on the burned areas, and on certain sites, especially northern slopes, there is a mixture of hemlock and hardwoods. On the whole, the density of stocking is below average for the region."

Ackerman Run--"This area has been logged at least once, and is now almost completely covered with a second-growth stand of northern hardwoods 40 to 50 years of age. On the northern exposures, there is a relatively high percentage of hemlock. Taken as a whole, the density of stocking is about average for the region."

Hemlock Run--"This watershed, like Ackerman Run, of which it is a tributary, supports a relatively good stand composed chiefly of second-growth northern hardwoods from 40 to 50 years of age. The most important difference in cover is that Hemlock Run has a higher percentage of hemlock. This species occurs in almost pure stands on certain sites, especially northern or western slopes. The density of stocking is average or above for the region."

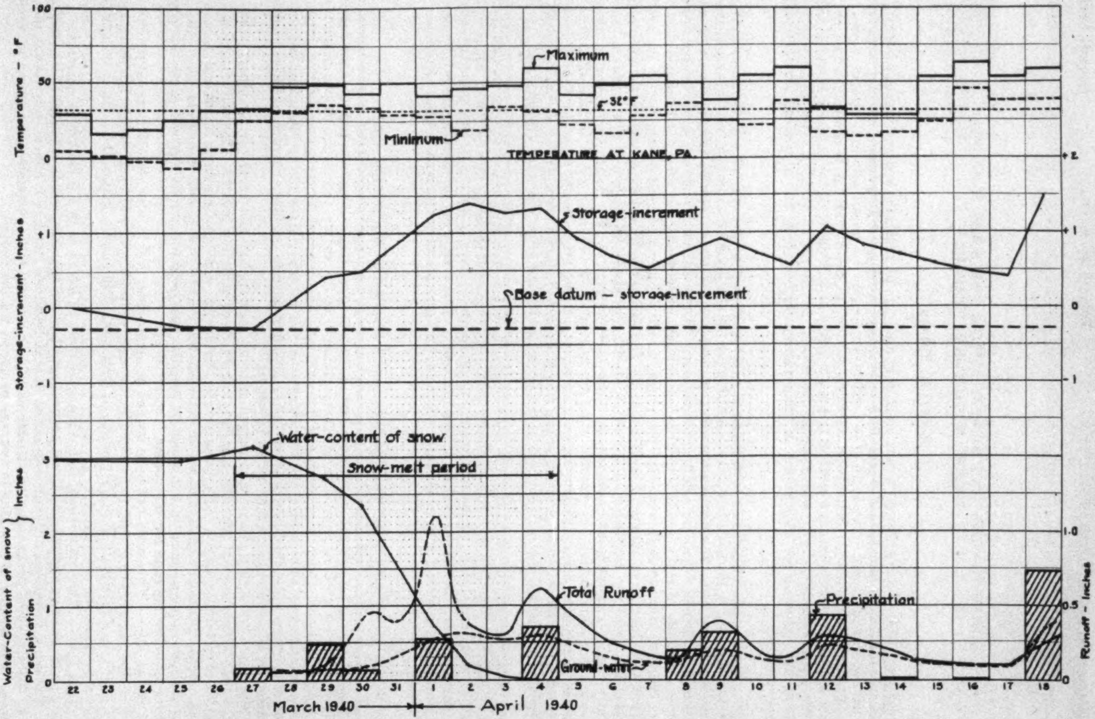

Fig. 1--Hydrologic phenomena, melting-snow period, Gilfoyle Run, Elk County, Pennsylvania

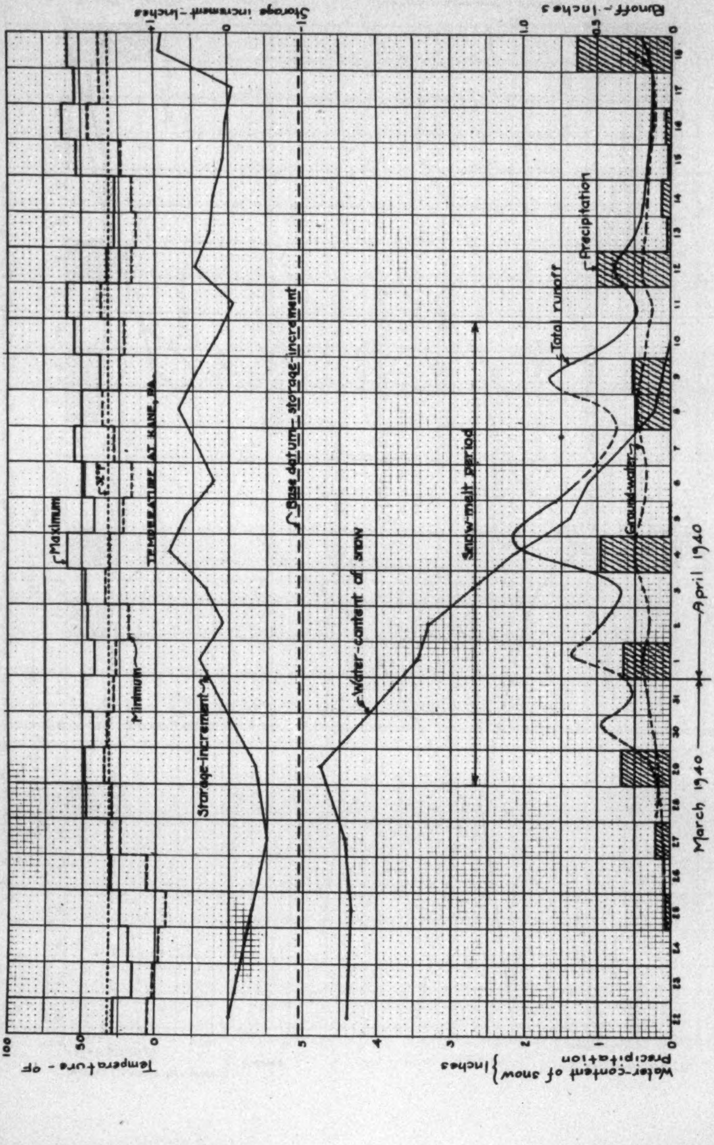

Fig. 2--Hydrologic phenomena, melting-snow period, McKee Run, Elk County, Pennsylvania

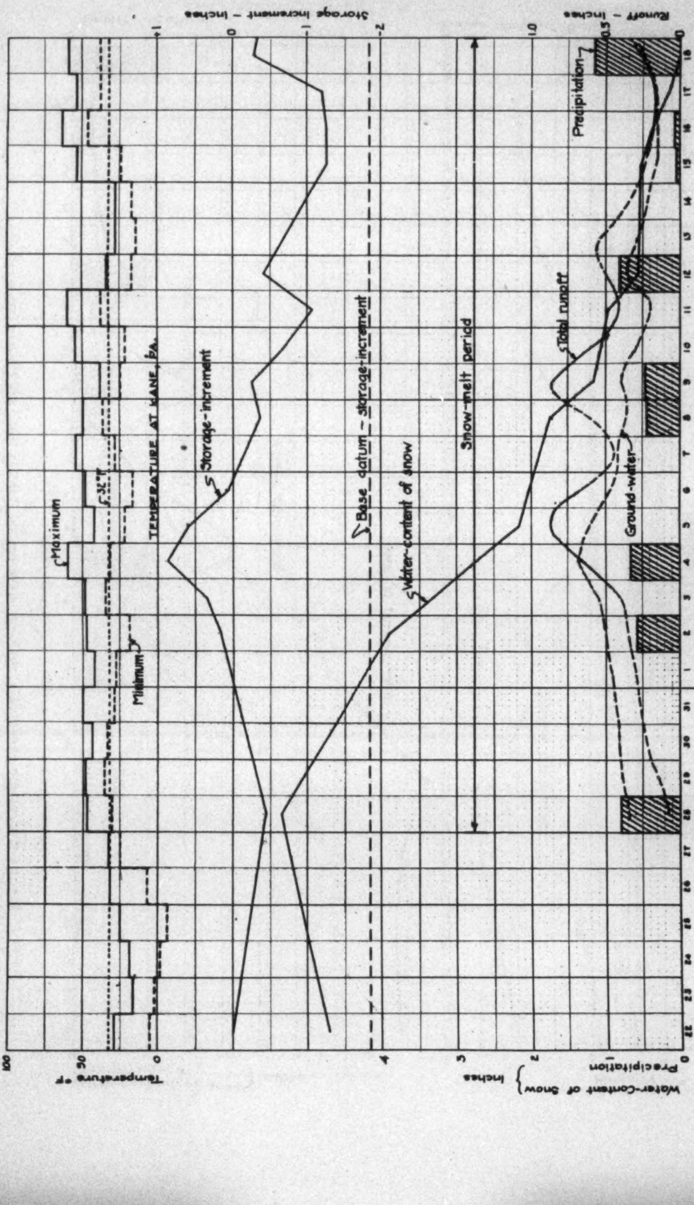

Fig. 3--Hydrologic phenomena, melting-snow period, Ackerman Run, Elk County, Pennsylvania

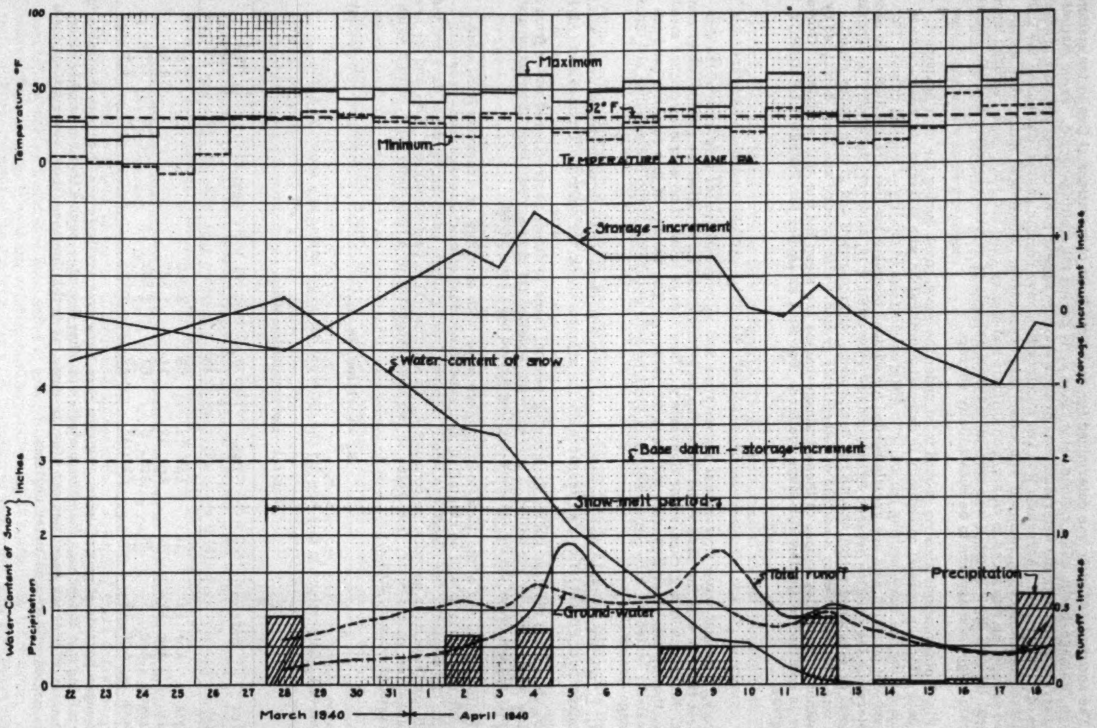

Fig. 4--Hydrologic phenomena, melting-snow period, Hemlock Run, Elk County, Pennsylvania

The accumulated snow was determined for each area from observations at five to ten stations in each drainage-basin, observations being taken daily during the melting-period. From statistical analysis of the data the determinations of snow-storage appear to be correct within a probable range of ± 10 per cent. Ackerman Run and Hemlock Run have regular gaging-stations of the United States Forest Service, equipped with water-stage recorders. Thin-edged weirs were established across the entrances to culverts on Gilfoyle and McKee runs and staff-gage readings taken several times a day. Rainfall was determined from records of several recording and non-recording rain-gages and appears to be substantially correct.

Field-observations show no ground frost under the snow-cover during the melting-period. The data afford an unusual opportunity to determine infiltration with unfrozen but snow-covered ground during the snow-melting period, with different degrees of density of vegetal cover. This is a subject on which data are greatly needed for various purposes but few are available. In order to determine the relation between infiltration and snow-melt it is, however, necessary to separate the total or measured runoff into its two components, surface-runoff and ground-water runoff. This was accomplished by a method of determining ground-water storage and flow, developed by the author. The valley-slopes of these drainage-basins are steep and the soil is shallow. Ground-water is confined to shallow hill-slope aquifers. For such an aquifer the POISEUILLE-DARCY, law gives

$$y_g = y_0 e^{-k_g t} \qquad \text{(1)}$$

where y_0 = ground-water flow-rate at a given time and y_g = ground-water flow-rate at the subsequent time t; e is the base of the Napierian logarithms, and k_g is called the ground-water constant. Starting with a ground-water flow-rate y_0, then t days later, if no accretion occurs meanwhile, the ground-water flow-rate will have the value y_g. The validity of this equation has been extensively tested for hill-slope aquifers of the type here occurring in the Susquehanna and other drainage-basins [2].

C. L. WICHT [3] found that equation (1) applied to hill-slope aquifers in drainage-areas within the Jonkershoek Forest Influences Research Station at Jonkershoek, Stellenbosch, Union of South Africa.

If, as is often the case during the growing season, there is direct abstraction of water from a shallow water-table by vegetation, a correction to equation (1) is required. Such abstraction apparently did not occur during the snow-melting period here considered.

Following the end of the snow-melting there were, with exception of Ackerman Run, a few days for each stream with no rainfall or appreciable residual channel-storage from preceding runoff. Consequently the runoff was wholly derived from ground-water during these days and the runoff for these days permits the constant k_g in equation (1) to be determined. If q_2 and q_1 are the measured ground-water flow-rates on two days separated by a time-interval t, within which no accretion occurs, then

$$k_g = (1/t) \log_e (q_1/q_2) \qquad \text{(2)}$$

Values of k_g determined in this way for the different drainage-basins are shown in Table 1.

Table 1--Determination of k_g

Area (1)	Date (2)	y_1 (3)	Date (4)	y_2 (5)	(y_1/y_2) (6)	t, days (7)	k_g (8)	Half-time (9)
Gilfoyle	Apr. 14	.16	Apr. 17	.08	2.000	3	.23	3.01
McKee	Apr. 15	.17	Apr. 17	.11	1.547	3	.14	4.94
Ackerman	Apr. 5	.86	Apr. 6	.67	1.282	1	.25	2.76
Hemlock	Apr. 14	.37	Apr. 17	.20	1.851	3	.20	3.45

Longer periods of ground-water regimen than were here available are of course desirable in determining k_g. It has been found from studies of other drainage-basins that reasonably close determination of these quantities can often be made, as in this instance, from observations for a single period with ground-water regimen.

Except for Ackerman Run the conditions were favorable to good determination of k_g. The "half-time" given in Column (9) of Table 1 is the time in days required for depletion of one-half of the initial ground-water storage, starting at any given date, if no accretion occurs meanwhile. This quantity is similar to the "half-time" of radioactive decay. These are numerically small half-times as compared with those obtained for most larger drainage-areas and indicate that because of steep slopes and relatively shallow permeable material comprising these aquifers, the ground-water is temporary or ephemeral and quickly drains out or becomes negligible in amount during periods with no accretion.

The integral of equation (1) from $t = 0$ to $t = \infty$ represents the total ground-water outflow, starting with an initial flow q_0 and with no subsequent accretion. This quantity must also represent the total ground-water storage at the beginning of the period. This leads to the important result, which also follows directly from POISEUILLE-DARCY'S law, that for a hill-slope aquifer where the slope of the water-table remains sensibly constant while the flow-rate changes, the rate of ground-water flow at a given time is directly proportional to the amount of ground-water storage Q_g or

$$q_g = k_g Q_g \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where k_g has the same value as in equation (1). This simple relation makes it possible to determine the ground-water flow-rate q_g at any time if the ground-water storage Q_g is known. Also if q_g is known at a given time, then

$$Q_g = (q_g/k_g) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

From the known ground-water flow for a few days after the end of the snow-melt, values of Q_g for a given date have been fixed for each drainage-basin, as in Table 2.

Table 2--Determination of terminal ground-water storage (inches)

Area (1)	k_g (2)	Date (3)	q_g (4)	Q_g (5)
Gilfoyle	.23	Apr.16	.10	0.434
McKee	.14	Apr.17	.11	0.79
Ackerman	.25	Apr.17	.16	0.64
Hemlock	.20	Apr.16	.23	1.15

Subsurface storage and flow--The line marked "Storage-increment" on each of Figures 1 to 4 was obtained as follows. The measured precipitation was corrected for rainfall-interception, using percentages derived from previous observations of interception by HORTON [4] and others. This gives the ground-rainfall. The mass ground-rainfall from the beginning of melting to the end of any given day of record was determined and added to the gain or loss of surface-storage, determined from the snow-surveys. Subtracting from this quantity for each day the mass-runoff during the same period, starting with the beginning of snow-melt, the remainder represents water unaccounted for either as runoff or as storage above ground and which therefore represents an increment or decrement of storage within the soil, either as ground-water storage below the water-table or capillary storage above the water-table, or both.

Temperatures were unusually low throughout the preceding winter, and with heavy snow-cover no water had entered the soil for several weeks. At the beginning of the melting-period the ground-water flow was low and, as shown later, there was some deficiency of capillary moisture in the soil above the water-table on three of the areas.

The values of ground-water storage Q_g previously given for a particular date on each area permit a datum-line of zero ground-water storage to be added to each diagram. The ground-water flow on any given date will then be equal to the intercept between this datum-line and the ground-water storage-increment line multiplied by the constant $(1/k_g)$ for the given area.

Initial capillary moisture-deficiency--The daily ground-water flow determined in this way is shown by the line marked "Ground-water flow". This line lies under the runoff-line in the right-hand portion of the melting-period but crosses the runoff-line on April 4 for Ackerman and Hemlock areas and on March 28 for the Gilfoyle and McKee areas. Preceding these dates the ground-water flow-line as computed lies above the actual runoff-line and this portion of the computed ground-water flow-line represents ground-water as it would have been if there had been no initial capillary deficiency at the beginning of the melting-period, in which case the entire increment of subsurface storage would have been added to ground-water accretion. Ground-water accretion cannot occur in general until any existing capillary deficiency is made up by infiltration. The actual runoff for the part of the diagram where the computed ground-water line lies above the measured runoff-line was entirely ground-water flow. The fact that the computed ground-water flow

exceeded the observed runoff shows that the ground-water flow was less than the amount corresponding to the total subsurface storage. The actual ground-water storage can be determined from the measured runoff at the beginning of the period by multiplying this quantity by ($1/k_g$). The difference between this and the total storage shown by the storage-increment line on any given date represents the remaining deficiency of capillary moisture. The total capillary deficiency determined in this way at the beginning of the melting-period for the different areas was as follows: Gilfoyle, 0.35 inch; McKee, 0.00 inch; Ackerman, 1.12 inches; and Hemlock, 1.00 inch. The increase of ground-water flow, as shown by the actual runoff during the period while capillary deficiency continued, shows that on these areas there was an accretion to ground-water storage before the capillary deficiency disappeared. This is easily understood from the fact that these are forested areas and underneath the protected crown-areas of trees, particularly needle-leaf trees, hemlock, spruce, and pine, much larger capillary deficiencies occur at the end of the growing season than in the open [5]. This is partly the result of interception, partly the result of exhaustion of soil-moisture within the root-zone of the tree. When infiltration occurs the capillary deficiency between trees will become zero and accretion to the water-table will take place while some capillary deficiency still remains under tree-crowns. Consequently in a mixed area both increase of capillary storage and accretion to the water-table may take place simultaneously without any violation of the rule that at a given spot they do not occur simultaneously.

Hydrologic balance-sheet--Using the methods of analysis described, the hydrologic balance-sheet was made up for each of the four areas, as shown by Table 3.

Table 3--Hydrologic balance-sheet, snow-melting period, streams in western Pennsylvania
(Data by United States Forest Service; analysis by Robert E. Horton; all quantities in inches or inches per day)

(1) Stream	Gilfoyle	McKee	Ackerman	Hemlock
(2) Cover	Thin	Thin	Good	Full
(3) Period	Mar. 27- Apr. 4	Mar. 29- Apr. 10	Mar. 28- Apr. 18	Mar. 28- Apr. 13
(4) Number of days	9	13	22	17
(5) Snow-storage	3.14	4.78	5.34	5.24
(6) Precipitation	2.00	3.33	5.01	4.16
(7) Total supply	5.14	8.11	10.35	9.40
(8) Interception, evaporation, etc., 10 per cent of (6)	10	10	10	10
(9) Loss	0.20	0.33	0.50	0.42
(10) Net supply	4.94	7.78	9.85	8.98
(11) Total runoff	3.20	6.70	9.06	7.77
(12) Ground-water: Total	1.53	2.31	6.82	6.47
(13) Ground-water: Average rate	0.17	0.18	0.31	0.38
(14) Surface-runoff =[(11) - (12)]	1.67	4.39	2.24	1.30
(15) Infiltration =[(10) - (14)]	3.27	3.39	7.61	7.68
(16) Time in hours	216	312	528	408
(17) Infiltration, average rate, inch per hour	0.015	0.011	0.014	0.019
(18) Ground-water-flow constant, k_g	0.23	0.14	0.25	0.20
(19) Storage, beginning of period	0.00	0.62	1.40	1.50
(20) Storage, end of period	1.25	1.14	1.55	1.97
(21) Δ_g	1.25	0.52	0.15	0.47
(22) Runoff (item 11)	3.20	6.70	9.06	7.77
(23) Δ, ground-water storage	1.25	0.52	0.15	0.47
(24) Moisture-deficiency	0.35	0.00	1.12	1.00
(25) Total	4.80	7.22	10.35	9.24
(26) Net supply (item 10)	4.94	7.78	9.85	8.98
(27) Difference, [(26) - (25)]	-0.14	-0.56	0.50	0.26

Lines 1 to 10 give the determination of the net supply available to produce either surface-runoff, ground-water runoff, or capillary or ground-water storage during the melting-period. It will be noted that the net available supply of water, line 10, ranged from 4.94 inches on the Gilfoyle Area to nearly ten inches on the Ackerman Area.

In lines 18 to 27 of Table 3, figures are given showing the balance between water available

and water disposed of. If all the data were precise and the computation correct, these two quantities should be equal. The increment of ground-water storage is given by line 21. The runoff for the melting-period plus ground-water storage plus initial moisture-deficiency, if any, represents the total water accounted for. The difference between this and the net supply, line 10, represents water unaccounted for. These differences are in each case less than ten per cent of the net supply and may be due to any one of several different things: Error in determination of snow-storage; errors in rainfall or stream-gaging; or estimated water-losses, particularly in case of the Hemlock Area, some uncertainty as to ground-water storage and flow. The important point is that these differences are not sufficient to have any important effect on the determination of infiltration-capacity.

Infiltration-capacity--Infiltration-capacity is the maximum rate at which a given soil can absorb rain or melt-water at a given time. It is like the carrying capacity of a pipe or electrical conductor--a volume per unit of time and not a total volume. Lines 11 to 17 of Table 3 contain data for determination of the average infiltration-rate during the snow-melting period. The results show a substantial amount of infiltration throughout the snow-melting period, ranging from about 0.25 to 0.5 inch of water absorbed per day. These quantities are not infiltration-capacities because of the fact that during a large part of the time the supply-rate was less than the infiltration-capacity--as shown by the fact that there were alternate increases and decreases of storage. A close approximation to the infiltration-capacities of these areas, with unfrozen soil under snow-cover, is obtainable by using data for the day on which the infiltration-rate was the highest. On these days storage accumulated above ground, showing that the supply exceeded surface-runoff plus infiltration. The determination of infiltration-capacity is based on the fact that the total infiltration in any time-unit must equal the increment of ground-water storage plus the ground-water outflow. Both these quantities are given on Figures 1 to 4, and the results are given in Table 4, and indicate that for each of these areas the infiltration-capacity was approximately 0.05 inch per hour or about 1.2 inches per day. These figures are in line with other values of infiltration-capacity in central United States for winter conditions but with unfrozen soil. (It should be noted that the fact that storage attained a maximum on different dates on each of these areas does not indicate either that the soil became saturated or even that the supply-rate equalled the infiltration-capacity. It merely shows that at the times of maximum storage, ground-water storage was built up to a point where the ground-water outflow plus surface-runoff became equal to the supply-rate from rainfall and the snow-melt.)

Table 4--Infiltration-capacity

Area (1)	Date (2)	Δ_g (3)	q_g (4)	Total (5)	Infiltration capacity (6)
				in	in/hr
Gilfoyle	Apr. 17	1.05	0.18	1.23	0.051
McKee	Apr. 17	1.00	0.13	1.13	0.047
Hemlock	Apr. 3	0.75	0.57	1.32	0.055
Ackerman	Apr. 18	0.91	0.22	1.13	0.047

Snow-melting constant--A computation was also made of the rate of snow-melt in inches per degree-day on the different areas, using temperatures at Kane Forest Experiment Station. The results, given on Table 5, show a larger melting-constant for the areas with smaller forest-density and the figures for denser forest are in line with the values of the snow-melting constant, ranging from 0.05 to 0.06 inch per degree-day temperature-excess above 32° as determined from laboratory and field experiments in other localities by HORTON [6] and CLYDE [7], under nearly comparable conditions.

Table 5--Snow-melting characteristics, streams in western Pennsylvania

(1) Stream	Gilfoyle	McKee	Ackerman	Hemlock
(2) Cover	Thin	Thin	Good	Full
(3) Period	Mar. 28-Apr. 1	Mar. 30 Apr. 5	Mar. 28-Apr. 5	Mar. 28-Apr. 9
(4) Number of days	5	7	9	13
(5) Amount of melt-water, inches	2.60	3.50	3.35	4.65
(6) Rate of melt-water, in/day	0.52	0.50	0.37	0.36
(7) Degree-days above 32°F[a]	31	39	57	80
(8) Degree-days per day	6.2	5.6	6.3	6.2
(9) Melt-water, inches/degree-day	0.084	0.088	0.059	0.058

[a] Mean of maximum and minimum at Kane, Pennsylvania.

While the results of this study are informative, the main purpose of the paper is to describe a methodology which it is hoped will be extended and applied in other cases. With adequate data it is possible to trace the entire hydrologic history of the snow-melting period from the snow-surface downward to the water-table. As here given, the method can be applied only if (1) a ground-water curve is available, (2) if ground-water storage can be determined at the beginning and end of the period. The analysis would be greatly facilitated if suitable ground-water-level records were available within the drainage-basin. Such records, together with the depletion-curve, can be used to determine the ground-water storage at the beginning and end of the record and also the dates and amounts of ground-water accretion.

The author is indebted to Dr. H. L. SHIRLEY and E. N. MUNNS of the United States Forest Service and to Dr. A. L. PATRICK of the United States Soil Conservation Service for permission to use the field-data on which the paper is based, and for carefully reading the manuscript and offering valuable suggestions.

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REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

(See also pp. 18, 58, 90, and 126)

ROBERT E. HORTON: Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Amer., v. 56, pp. 275-370, 40 figs., 1945.

In this paper HORTON has dealt quantitatively with the general problem of physical characteristics of stream-pattern and basin-drainage. Quantitative physiographic factors are described, objectively defined, and analyzed with respect to surface runoff, erosion, and sedimentation in the origin and development of stream-systems. The paper is well documented and well illustrated, and has considerable mathematical treatment combining theory with observations and many specific examples.

Four of the fundamental concepts are: (1) The law of stream-numbers--This expresses the relation between the number of streams of a given order (systematically and objectively determined by the degree of branching) and the stream-order in terms of an inverse geometric series. (2) The law of stream-lengths--This expresses the average length of streams of a given order in terms of stream-order, average length of streams of the first order, and the stream-length ratio, and takes the form of a direct geometric series. (3) Limiting infiltration-capacity--This is the maximum volume per unit-time which a soil in a given condition can absorb from falling rain. (4) Runoff-detention-storage relation--There is a definite functional relation between the depth of surface detention, or quantity of water accumulated on the soil-surface, and the rate of surface runoff or channel-inflow.

The most important single factor involved in connection with the development of stream-systems and their drainage-basins by aqueous erosion is the minimum length of overland flow required to produce sufficient runoff-volume to initiate erosion.

This important and valuable contribution by HORTON could have come only from a man of his varied and extensive experience and with his great breadth of vision.

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SIMPLIFIED PLOTTING OF STATISTICAL OBSERVATIONS

E. J. Gumbel

We consider the largest observation in a sample of size n and ask: What is the mean number of observations such that this value, or a larger one, happens once again? This question is important for statistical variates as earthquake magnitudes, precipitations, floods, temperatures, and pressures, where the largest value involves specific dangers. Similar problems arise in quality-control and in gunnery.

It will be shown that the mean number depends, in general, upon the nature of the variate. However, for a wide class of statistical distributions, it converges toward the sample-size. The general solution given in the first section will be applied, in the second section, to some interesting distributions; in the last section it will be used to simplify the plotting procedure advocated in a previous article [see 6 of "References" at end of paper].

Exact and asymptotic values of the occurrence-interval--We deal with an unlimited continuous variate x subject to a distribution f(x). The probability of a value equal to, or less than, x is F(x), and the theoretical return period T(x) of a value equal to, or larger than, x is

$$T(x) = 1/[1 - F(x)] \ldots\ldots\ldots\ldots (1)$$

provided that the observations are equidistant in time. The observations arranged in increasing magnitude are x_m (m = 1, 2, . . . n). Thus x_n is the largest observation. The observed return-period of a value equal to, or larger than, x_n will be called occurrence-interval [7]. The problem is how to determine this function of n. Until now, three methods have been used to solve this question. All three lead to results which cannot be accepted.

(a) We may attribute either the cumulative frequency (m/n) or the cumulative frequency [(m - 1)/n] to the m'th observation. Engineers commonly use a compromise-frequency [1, 8]

$$F(x_m) = [(m - 1/2)/n] \ldots\ldots\ldots\ldots (2)$$

which leads to the occurrence-interval

$$T(x_n) = 2n \ldots\ldots\ldots\ldots (3)$$

An event which has happened in n years, is supposed to happen in the mean in 2n years. Such a statement is hazardous and underestimates the danger involved in the happening of the largest value.

(b) Another method [1] is to choose the median as representative of the extreme value. The median $\breve{x}_n$ of the largest among n observations is the solution of $[F(\breve{x}_n)]^n = 1/2$. From (1) we obtain by expansion the occurrence-interval

$$T(\breve{x}_n) = 1\Big/\left\{(\log 2)/n - (\log 2)^2/(2n^2) + \cdots\cdots\right\}$$

This expression converges toward

$$T(\breve{x}_n) = 1.443n + 1/2 \ldots\ldots\ldots\ldots (4)$$

The occurrence-interval (4) is 44 per cent greater than the number of observations, a result which can hardly be justified. Figure 1 shows in a double logarithmic scale the occurrence-intervals (3) and (4) as functions of the number of observation n.

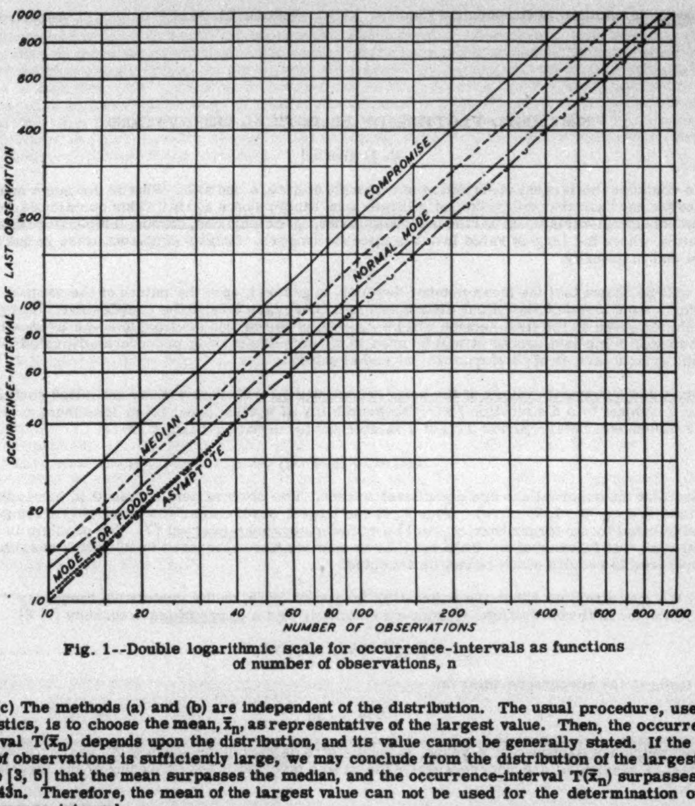

Fig. 1--Double logarithmic scale for occurrence-intervals as functions of number of observations, n

(c) The methods (a) and (b) are independent of the distribution. The usual procedure, used in statistics, is to choose the mean, $\bar{x}_n$, as representative of the largest value. Then, the occurrence-interval $T(\bar{x}_n)$ depends upon the distribution, and its value cannot be generally stated. If the number of observations is sufficiently large, we may conclude from the distribution of the largest value [3, 5] that the mean surpasses the median, and the occurrence-interval $T(\bar{x}_n)$ surpasses $1 \cdot 443n$. Therefore, the mean of the largest value can not be used for the determination of the occurrence-interval.

In the following we apply R. A. FISHER'S principle of maximum likelihood and use the mode $\tilde{x}_n$ of the largest value for the calculation of the occurrence-interval. For reasons of symmetry we calculate also the mode $\tilde{x}_1$ of the smallest value.

The distributions $w(x_n, n)$ and $w(x_1, n)$ of the largest and of the smallest value are

$$w(x_n, n) = nF(x)^{n-1} f(x) \qquad w(x_1, n) = n[1 - F(x)]^{n-1} f(x) \quad \ldots\ldots\ldots\ldots (5)$$

If the distributions (5) possess modes $\tilde{x}_n$ and $\tilde{x}_1$ they are the solution of

$$(n-1)[f(\tilde{x}_n)/F(\tilde{x}_n)] = -[f'(\tilde{x}_n)/f(\tilde{x}_n)] \qquad (n-1)[f(\tilde{x}_1)]/[1 - F(\tilde{x}_1)] = [f'(\tilde{x}_1)/f(\tilde{x}_1)] \quad \ldots\ldots (6)$$

$$(n-1) = -[f'(\tilde{x}_n) F(\tilde{x}_n)]/f^2(\tilde{x}_n) \quad \text{or} \quad (n-1) = [f'(\tilde{x}_1)[1 - F(\tilde{x}_1)]/f^2(\tilde{x}_1) \quad \ldots\ldots (7)$$

The probabilities $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ obtained from these equations will be called adjusted frequencies

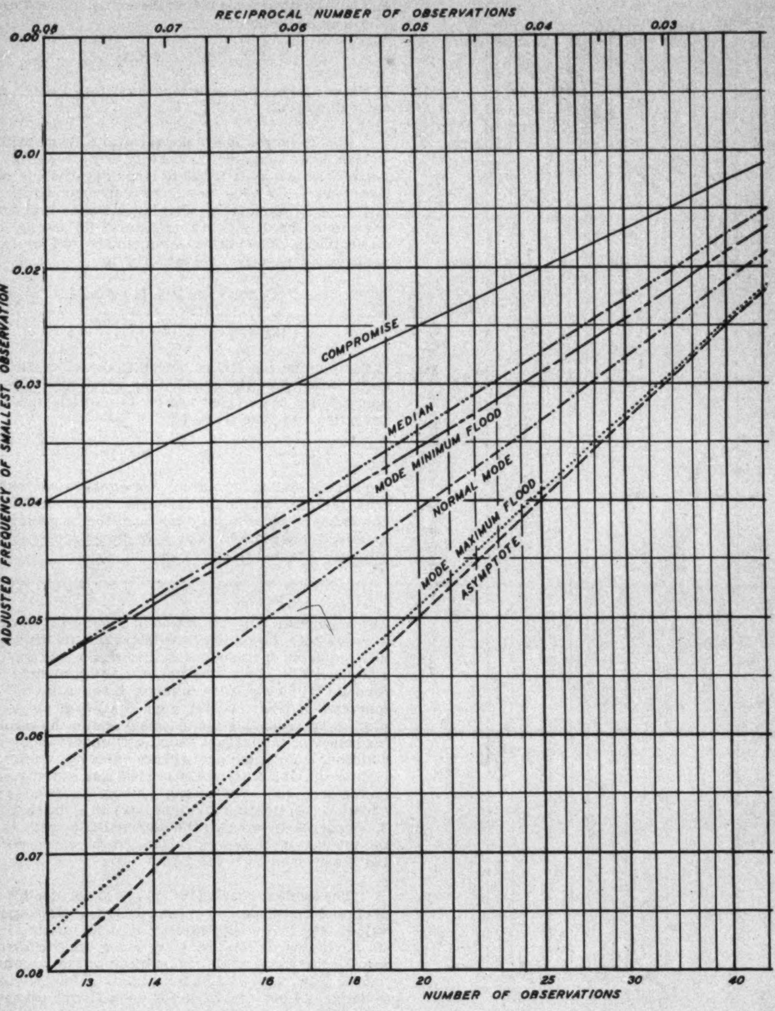

Fig. 2--Occurrence-intervals and asymptotic adjusted frequencies of extreme value $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ as function of number of observations, n (Fig. 2 concluded on next page)

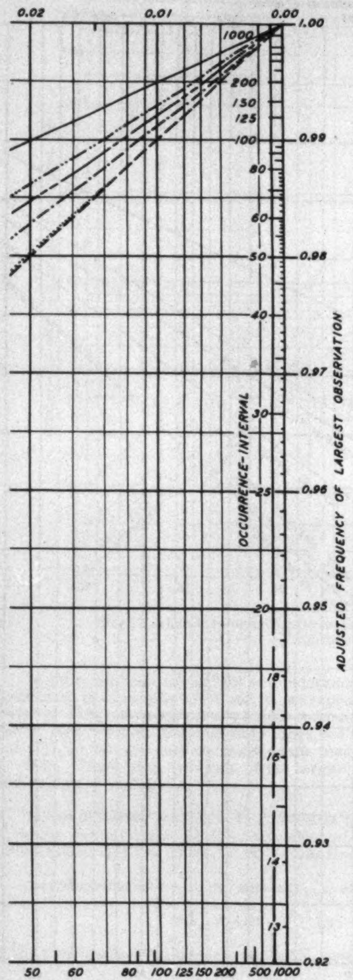

Fig. 2--Concluded (first part of Fig. on preceding page)

and will be used for plotting the extreme members of a sample. Finally

$$T(\tilde{x}_n) = 1/[1 - F(\tilde{x}_n)] \quad \ldots\ldots\ldots \quad (8)$$

is the occurrence-interval. This solution holds for any value of n.

If n is large, and if the variate x is unlimited in both directions, the probability $F(x)$ tends to zero (or unity) as x tends to large negative (or positive) values. In both cases, the distribution $f(x)$ converges toward zero. For large numbers of observations the quotients in equations (6) become indeterminate. The customary methods lead for large positive (or negative) values of x to

$$\left.\begin{aligned} -f'(x)/f(x) &= \lim_{x=\infty} f(x)/[1 - F(x)] \\ f'(x)/f(x) &= \lim_{x=-\infty} f(x)/F(x) \end{aligned}\right\} \quad \ldots\ldots \quad (9)$$

If the distribution $f(x)$ is such that these equations hold, the asymptotic adjusted (or corrected) frequencies for the largest and for the smallest observations become from (7)

$$F(\tilde{x}_n) \rightarrow [1 - (1/n)] \qquad F(\tilde{x}_1) \rightarrow (1/n) \quad \ldots \quad (10)$$

We expect that (n - 1)-values are equal to, or less than, the mode of the largest observation, and that one value is equal to, or less than, the mode of the smallest observation. The asymptotic occurrence-interval obtained from (1) and (10) is

$$T(\tilde{x}_n) \rightarrow n \quad \ldots\ldots\ldots\ldots \quad (10')$$

The asymptote (10′) is plotted in Figure 1. Figure 2 shows both the occurrence-intervals and the asymptotic adjusted frequencies of the extreme values $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ as a function of n. According to formula (10) we plot the adjusted frequencies as functions of (1/n). On the right (left) ordinate we plot, in an ascending (descending) scale, the adjusted frequency of the largest (smallest) observation. In addition, we plot the occurrence-intervals on the right ordinate. This scale is identical with the scale on the abscissa. Therefore, the compromise (3) and equation (10) become straight lines in Figures 1 and 2. Figure 2 shows also the adjusted frequency for the median of the largest value and the corresponding occurrence-interval (4).

The evident result (10′) is a justification for the choice of the mode as representative of the largest value. The larger the number of observations, the larger the error introduced by using the compromise (3), the median (4), or the mean of the largest value. The error is 100 per cent of n for the compromise, 44 per cent of n for the median, and more than 44 per cent for the mean.

Thus, for a large number of observations, the occurrence-interval is equal to the number of observations. If we have made n observations, we may expect, for n sufficiently large, that the largest value of this sample, or a larger one, happens again after n new observations. Equations (10) and (10′) may also be interpreted in the following way: The value x of the variate to which a return-period T corresponds, converges toward the most probable value for this number of observations. A graph which shows the variate as a function of the return-period, may be interpreted, for large n, as showing the most probable value as a function of the number of observations.

However, formula (10′) interpreted as an equation holds only for n large. For a small number of observations, the occurrence-interval $T(\tilde{x}_n)$ will, in general, differ from n. To obtain the relationship between the occurrence-interval and the number of observations, use (1) in the form

$$T(\tilde{x}_n) - 1 = F(\tilde{x}_n)/[1 - F(\tilde{x}_n)]$$

whence from (7)

$$[T(\tilde{x}_n) - 1]/(n - 1) = -\left\{ f(\tilde{x}_n)/[1 - F(\tilde{x}_n)][f(\tilde{x}_n)/f'(\tilde{x}_n)]\right\} \ldots\ldots\ldots\ldots (11)$$

The right member of the equation (11) is a function of the most probable largest value $\tilde{x}_n$, or by virtue of (7), a function of the number of observations. The condition

$$\left\{d \log[1 - F(x)]/d \log f(x)\right\} \gtreqless 1 \ldots\ldots\ldots\ldots (12)$$

obtained from (11) decides whether the occurrence-interval, with increasing n, decreases or increases toward the number of observations. However, the convergence of the occurrence-interval toward n need not be monotonic, and may be very slow.

The relation

$$T(\tilde{x}_n) \gtrless n \ldots\ldots\ldots\ldots (13)$$

means: If a sample of size n has led to a largest observation x_n, we may expect in a second sample that this observation, or a larger one, happens after more (or less) than n observations. The unequality $T(\tilde{x}_n) < n$ may be interpreted so that, if a sample of size n has led to a largest observation x_n, we may expect a larger observation in a second sample of the same size.

Some distributions--The convergence (10) is by no means self-evident. Consider, for example, PARETOS' distribution

$$F(x) = (1 - x^{-k}) \qquad f(x) = kx^{-k-1} \qquad f'(x) = -[(k+1)f(x)/x] \qquad T(x) = x^k \quad \text{for } x \geq 0 \text{ and } k > 1 \text{ .(14)}$$

then the condition (9) is not fulfilled and, from (11), for all values of x

$$[T(x) - 1]/(n - 1) = k/(k + 1) \ldots\ldots\ldots\ldots (15)$$

The occurrence-interval always falls short of the number of observations. The condition (9) is necessary and sufficient for the convergences (10) and (10′).

For the distributions, which we shall consider now, the condition (9) is fulfilled. To see the difference between the occurrence-intervals $T(\bar{x}_n)$ and $T(\tilde{x}_n)$, which result from the use of the mean and the mode of the largest observation, consider an exponential distribution

$$F(x) = [1 - \exp(-x)] \qquad f(x) = [1 - F(x)] \qquad f'(x) = -f(x) \qquad T(x) = \exp(x) \quad \text{for } x \geq 0 \ldots (16)$$

The mean $\bar{x}_n$ of the largest observation [4] converges towards

$$\bar{x}_n = \log n + 0.57722$$

and the corresponding occurrence-interval obtained from (16) becomes

$$T(\bar{x}_n) = 1.781\, n \ldots\ldots\ldots\ldots (17)$$

On the other hand, condition (9) holds for all values of x. The occurrence-interval $T(\tilde{x}_n)$ is equal to the number of observations.

In the following we consider two distributions which show a similar behavior as the exponential distribution. For the distribution of the floods we may write [5]

$$F(x) = \exp(-e^{-y}) \qquad f(x) = \alpha \exp(-y-e^{-y}) \qquad f'(x) = f(x)\,(-1+e^{-y}) \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\; (18)$$

where

$$y = \alpha(x-u) \;.\; (18')$$

is a reduced flood. The mode of the largest reduced flood obtained from (7) and (18) is

$$\tilde{y}_n = \log n$$

and the adjusted frequency $F(\tilde{x}_n)$ of the largest flood obtained from (18) is

$$F(\tilde{x}_n) = \exp(-1/n) \;.\; (19)$$

Finally, the occurrence-interval is

$$T(\tilde{x}_n) = (n + 1/2) \;.\; (20)$$

provided that $n^2 \gg 1$. This occurrence-interval is traced in Figures 1 and 2 as a function of n. Figure 3 shows the quotient $[T(\tilde{x}_n)/n]$ for small values of n. The occurrence-interval diminishes rapidly toward the number of observations.

The adjusted frequency $F(\tilde{x}_1)$ of the smallest flood obtained from (7) and (18) is the solution of

$$n = 1/F(\tilde{x}_1) + 1/[F(\tilde{x}_1)\log F(\tilde{x}_1)] - 1/\log F(\tilde{x}_1) \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\; (19')$$

To facilitate the use of formulas (19) and (19′) we choose numerical values for the adjusted frequency $F(\tilde{x}_1)$ of the smallest flood [Column (2) of Table 1], calculate from (19′) the corresponding number of observations and, from (19), the adjusted frequency $F(\tilde{x}_n)$ of the largest flood [Column (3)]. For a given number of observations the plotting positions of the largest and smallest floods are obtained by linear interpolation between reciprocals of n. The adjusted frequencies $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ of the largest and smallest flood are traced in Figure 2 as functions of n. Both frequencies approach the asymptotic frequencies (10). However, the approach of $F(\tilde{x}_n)$ is quicker than the approach of $F(\tilde{x}_1)$. This difference is due to the fact that the distribution of the floods is asymmetrical.

Table 1--Adjusted frequencies of smallest and of largest floods

Inverse number of observations (1/n) (1)	Adjusted frequencies of Smallest flood $F(\tilde{x}_1)$ (2)	Largest flood $F(\tilde{x}_n)$ (3)
.081580	.055	0.92166
.073219	.050	0.92940
.065025	.045	0.93704
.057000	.040	0.94459
.049147	.035	0.95204
.041472	.030	0.95938
.033982	.025	0.96659
.026685	.020	0.97367
.019596	.015	0.98059
.018205	.014	0.98196
.016824	.013	0.98332
.015452	.012	0.98467
.014090	.011	0.98601
.012739	.010	0.38734
.011398	.009	0.98867
.010069	.008	0.98998
.0087514	.007	0.99129
.0074469	.006	0.99258
.0061561	.005	0.99386
.0048804	.004	0.99513
.0036216	.003	0.99639
.0023826	.002	0.99762
.0011691	.001	0.99883
.0000000	.000	1.00000

For the logistic distribution

$$\left.\begin{aligned} F(x) &= 1/[1+\exp(-x)] \\ f(x) &= F(x)[1-F(x)] \\ f'(x) &= f(x)[1-2F(x)] \\ T(x) &= \exp(x) + 1 \end{aligned}\right\} \;.\;.\;.\;.\;.\; (21)$$

which is symmetrical, the adjusted frequencies of the extreme values, obtained from (7) are

$$F(\tilde{x}_n) = 1 - F(\tilde{x}_1) = 1 - 1/(n+1)$$

and the occurrence-interval obtained from (1) is

$$T(\tilde{x}_n) = (n+1) \;.\;.\;.\;.\;.\;.\;.\;.\;.\; (22)$$

a result which is similar to (20). Figure 3 shows the quotient $[T(\tilde{x}_n)/n]$ as a function of n. The mode of the largest value

$$\tilde{x}_n = \log n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22')$$

holds for the exponential distribution (16), the distribution of the reduced floods (18) and the logistic distribution (21).

For the distributions just considered the approach of the occurrence-interval toward the number of observations is rapid. This does not hold for the normal distribution

$$F(x) = \left\{[1 + \Phi(x)]/2\right\} \qquad f(x) = \exp(-x^2)/\sqrt{\pi} \qquad f'(x) = -2x\,f(x) \quad \ldots\ldots\ldots \quad (23)$$

where $\Phi(x)$ stands for the Gaussian integral. From equation (7) the adjusted frequency $F(\tilde{x}_n)$ of the largest observation is obtained as the solution of

$$(n - 1) = 2\tilde{x}_n[1 + \Phi(\tilde{x}_n)]/2f(\tilde{x}_n) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

We choose numerical values for $\tilde{x}_n = -\tilde{x}_1$ [Table 2, Column (1)], take the values $[1 + \Phi(\tilde{x}_n)]$ and $2f(\tilde{x}_n)$ from tables of the normal probability-function [11], and calculate n [Column (3)] from equation (24). The second column gives the adjusted frequencies $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ of the largest and of the smallest observation as a function of n. For given n we obtain the adjusted frequencies of the extreme observations by interpolating between reciprocals of n [Column (4)].

Table 2--Adjusted frequencies of extreme normal observations

Extreme value $\tilde{x}_n = -\tilde{x}_1$ (1)	Adjusted frequency $F(\tilde{x}_n) = 1 - F(\tilde{x}_1)$ (2)	Number observations n (3)	Reciprocal (1/n) (4)	Occurrence interval $T(\tilde{x}_n)$ (5)
1.00	.92135	9.8782	.1012	12.71
1.05	.93122	11.439	.08742	14.54
1.10	.94010	13.293	.07523	16.69
1.15	.94806	15.504	.06450	19.25
1.20	.95516	18.149	.05510	22.30
1.25	.96145	21.325	.04689	22.94
1.30	.96700	25.151	.03976	30.30
1.35	.97188	29.778	.03358	35.56
1.40	.97614	35.392	.02826	41.91
1.45	.97989	42.232	.02368	49.60
1.50	.98305	50.595	.01976	59.01
1.55	.98581	60.858	.01643	70.47
1.60	.98871	73.502	.01361	84.53
1.65	.990188	89.140	.01122	101.9
1.70	.991895	108.55	.009212	123.4
1.75	.993336	132.80	.007530	150.0
1.80	.994545	163.04	.005813	183.3
1.85	.995555	201.09	.004973	225.0
1.90	.996395	249.08	.004015	277.4
1.95	.997090	309.87	.003227	343.6
2.00	.997661	387.19	.002583	427.5
2.10	.998510	612.53	.001633	671.2
2.20	.9990686	986.39	.001014	1074
2.30	.9994284	1617.2	.0006184	1750
2.40	.9996557	2699.0	.0003705	2904
2.50	.9997965	4590.8	.0002178	4914
2.60	.9998820	7950.8	.0001258	8475
2.70	.99993228	14027	.00007129	14890
2.80	.99996249	25213	.00003966	26662
2.90	.99997945	46176	.00002166	48663
3.00	.99998895	86174	.00001160	90500

The last column gives the occurrence-interval $T(\tilde{x}_n)$, obtained from Column (2) by the use of equation (1). The occurrence-interval $T(\tilde{x}_n)$ as a function of n is traced in Figures 1 and 2. The adjusted frequency of the extreme observations is nearly a straight line. The asymptotic frequencies (10) are too small for the largest value and too large for the smallest value. The compromise frequencies (2) are too large for the largest value and too small for the smallest value. The occurrence-interval (3) is too large and the asymptote (10′) is too small.

Multiplication of the numbers in Columns (4) and (5) leads to the quotient $[T(\tilde{x}_n)/n]$, which is traced in Figure 3 as a function of n. For 1000 observations the occurrence-interval surpasses the number of observations by nine per cent. For 100,000 observations the percentage decreases to five per cent.

Combination of Columns (1) and (3) leads to the most probable largest and smallest normal value as a function of the number of observations. The unity of the extreme values is the standard deviation multiplied by $\sqrt{2}$. To find adequate scales for plotting $\tilde{x}_n$ as a function of n we introduce the asymptotic expression

$$1 - \Phi(x) = \exp(-x^2)/\left\{x\sqrt{\pi}\,[1 + (1/2x^2)]\right\} \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

into (24). Then the mode $\tilde{x}_n$ converges [9] toward

$$\tilde{x}_n{}^2 = \log n - \log(2\sqrt{\pi}) \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Graph (4) compares the mode and the mean of the extreme observation in a sample of size n. According to equation (26), we plot the square of the extreme value on the ordinate, and use a logarithmic scale for the abscissa. The mean $\bar{x}_n$ of the largest observation, calculated by L. H. C. TIPPETT [10], surpasses the mode.

According to (25), the quotient (11), namely

$$[T(\tilde{x}_n) - 1]/[n - 1] = 2\exp(-\tilde{x}_n{}^2)\ /\left\{\sqrt{\pi}\,[1 - \Phi(\tilde{x}_n)]\,2\tilde{x}_n\right\} \ldots\ldots\ldots\ldots$$

is larger than unity. To see analytically how the occurrence-interval converges toward n, we use (24) and obtain from (25) and (26) for sufficiently large values of n

$$T(\tilde{x}_n) = n\left\{1 + 1/2[\log n - \log(2\sqrt{\pi})]\right\} \ldots\ldots\ldots\ldots\ldots\ldots (27)$$

The occurrence-interval decreases toward the number of observations as $(1/\log n)$ converges toward zero. This is the analytic reason why the approach of $T(x_n)$ toward n is slow.

The adjusted frequency of the m'th observation--We know from (7) which adjusted frequencies must be attributed to the largest and to the smallest observation. This leads to a simple solution of the general questions of attributing a frequency and a return-period to the m'th observation. Although the two questions are equivalent, they imply different precisions. Let the frequency $F(x_m)$ of the m'th value be of the order 0.95 with an error of less than one per cent, $0.95 < F(x_m) < 0.9595$, then the observed return-period $T(x_m)$ obtained from (1) is $20 < T(x_m) < 24.69$. The error in the determination of the return-period is of the order 23 per cent, whereas the error in the frequency was one per cent. Therefore, a method which is sufficiently precise for the determination of the frequency may be insufficient for the observed return-period.

The m'th observation x_m in a sample of size n taken from a population with an initial distribution f(x), has another distribution which may be characterized by its mean, median, or mode.

In a preceding paper [6], we assumed that what has been observed was the most probable event. Consequently, we choose the modes $\tilde{x}_m$ as representatives of the m'th values. This choice of $F(\tilde{x}_m)$ as adjusted frequency is possible if all distributions of the m'th value possess modes, a condition imposed upon the initial distribution. However, this procedure requires the separate calculation of the n adjusted frequencies, an operation which is tiresome if n is large.

In the following, this procedure will be simplified. Let $\hat{x}_m$ be a representative m'th value. The probability $F(\hat{x}_m)$ of a value equal to, or less than, $\hat{x}_m$ may be used as adjusted frequency of the m'th observation, provided two conditions are fulfilled. First, the adjusted frequency must be

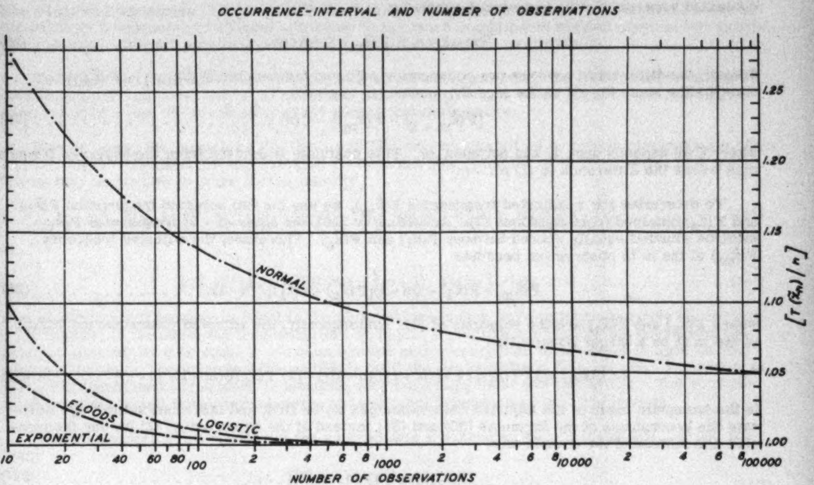

Fig. 3--$[T(\tilde{x}_n)/n]$ as function of number of observations, n

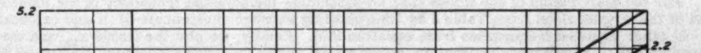

Fig. 4--Comparison of mode and mean extreme observation in sample of size n contained between the two observed frequencies

$$[(m-1)/n \le F(\hat{x}_m) \le (m/n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

Second, the differences between two consecutive adjusted frequencies $F[(\hat{x}_{m+1}) - F(\hat{x}_m)]$ must be the same for all ranks once the number n is given

$$[F(\hat{x}_{m+1}) - F(\hat{x}_m)] = C(n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (29)$$

where C(n) depends upon n and not upon m. This postulate is derived from the observed frequencies where the difference is (1/n).

To determine the n adjusted frequencies $F(\hat{x}_m)$, we use the two adjusted frequencies $F(\tilde{x}_1)$ and $F(\tilde{x}_n)$ obtained from equations (7). According to (29), the other (n - 2) frequencies $F(\hat{x}_m)$ must be situated equally spaced between $F(\tilde{x}_1)$ and $F(\tilde{x}_n)$. Therefore, the adjusted frequency $F(\hat{x}_m)$ of the m'th observation becomes

$$F(\hat{x}_m) = F(\tilde{x}_1) + (m-1)[F(\tilde{x}_n) - F(\tilde{x}_1)]/(n-1) \quad \ldots\ldots\ldots\ldots\ldots \quad (30)$$

where $F(\tilde{x}_n)$ and $F(\tilde{x}_1)$ are the solutions of (7). Consequently, the adjusted return-period $T(\hat{x}_m)$ of the m'th or a larger observation

$$1/T(\hat{x}_m) = [1/T(\tilde{x}_1)]\left\{1 - [(m-1)/(n-1)]\right\} + [1/T(\tilde{x}_n)][(m-1)/(n-1)] \quad \ldots\ldots \quad (31)$$

is the harmonic mean of the adjusted return-periods of the first and last observation. We advocate the general use of the formulas (30) and (31) instead of the compromise (2) for the frequencies and instead of the compromise

$$T(x_m) = n/[n - m + (1/2)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (31')$$

for the observed return-periods.

For the distribution of the floods (18) we determine the adjusted frequency of the smallest and of the largest flood from Table 1 by interpolating between reciprocals of n and calculate the (n - 2) other adjusted frequencies from equation (30). Finally, we plot the floods x_m and the frequencies $F(\hat{x}_m)$ on adequate probability-paper which shows the return-periods. The short method advocated here leads to frequencies which are practically identical with those calculated in our previous paper [6]. However, the amount of labor saved is considerable if n is large.

For a symmetrical distribution, the (n - m + 1) observation is related to the m'th observation by

$$F(\hat{x}_{n-m+1}) = [1 - F(\hat{x}_m)] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (32)$$

and the equation (30) becomes

$$F(\hat{x}_m) = F(\tilde{x}_1) + (m-1)(1 - 2F(\tilde{x}_1)/(n-1) \quad \ldots\ldots\ldots\ldots\ldots \quad (30')$$

For m = n we obtain, of course, $F(\tilde{x}_n) = [1 - F(\tilde{x}_1)]$. For an odd number n and for the rank $m = [(n+1)/2$ the adjusted frequency $F(\hat{x}_m) = (1/2)$ is the frequency of the median. For a symmetrical distribution it is sufficient to calculate the adjusted frequencies (30') up to the median. The other frequencies are obtained from the symmetry-relation (32).

For normal observations we determine the adjusted frequency of the smallest observation from Table 2 by interpolating between reciprocals of n and calculate the (n - 1) other adjusted frequencies $F(\hat{x}_m)$ from equations (30') and (32). Finally, we plot the points x_m, $F(\hat{x}_m)$ on normal probability-paper. For example, for ten normal observations, (1/n) = 0.1 we obtain from Table 2 $F(\tilde{x}_1) = 0.0779$ whence, from (30')

$$F(\hat{x}_m) = 0.07779 + (m-1)0.09382 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

From (31) we obtain the adjusted return-periods

$$T(\hat{x}_m) = 1/[1.01603 - 0.09382m] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (33')$$

The adjusted frequencies (33) given in Table 3, Line (6), differ only in the third decimal from the adjusted frequencies calculated according to the more complicated method given in our previous paper [6]. For all practical purposes these differences are negligible.

The formulas (30) to (32) allow the plotting of the smallest and of the largest observation, lead to one, and only one, series of observed points which ought to be situated on a straight line, and give a test for the validity of the theoretical distribution.

If n is large, the formulas (30), (30′), and (31) may be simplified by introducing equation (10). The asymptotic adjusted (or approximate) frequencies $F(\hat{x}_m)$ for the m′th observation thus obtained may be written in three forms, namely

$$F(\hat{x}_m) = (m/n) - [m-1]/[n(n-1)] = [(m-1)/n] + [n-m]/[n(n-1)] \quad \ldots\ldots\ldots\ldots (34)$$

or

$$F(\hat{x}_m) = [m-(1/2)]/n + \left\{[(n+1)/2] - m\right\}/[n(n-1)] \quad \ldots\ldots\ldots\ldots (34')$$

The approximate frequency is equal to the observed frequency (m/n) minus a positive correction, or it is equal to the observed frequency[(m - 1)/n] plus a positive correction (the correction depending upon m), or it is equal to the compromise plus a correction which depends upon m, but changes its sign. The formulas (34) and (34′) fulfil the two conditions (28) and (29). According to (34′), the approximate frequency is identical with the compromise for the median. The compromise gives too small frequencies before, and too large frequencies after, the median.

For the numerical calculation of the approximate frequencies we use instead of (34) the formula

$$F(\hat{x}_m) = (1/n) + (m-1)(n-2)/[n(n-1)] \quad \ldots\ldots\ldots\ldots (34'')$$

The asymptotic adjusted or approximate return-periods obtained from (34) are

$$T(\hat{x}_m) = [n - m + (m-1)/(n-1)] \quad \ldots\ldots\ldots\ldots (35)$$

For m = 1 and m = n we obtain

$$T(\hat{x}_1) = [n/(n-1)] \qquad T(\hat{x}_n) = n \quad \ldots\ldots\ldots\ldots (36)$$

in accordance with formula (10′). Thus, the asymptotic adjusted return-periods pass for increasing values of the variate from the exceedance-interval to the recurrence-interval, whereas the usual compromise (31′) is always contained between the two curves (see Fig. 6). The formulas (34) and (35) may safely be used for continuous, unlimited, and fairly symmetrical distributions, provided that the number of observations is large, a condition which depends upon the distribution.

For ten normal observations the different frequencies, namely, the two observed frequencies (m/n) and [(m - 1)/n], the compromise{[m - (1/2)]/n}, the adjusted frequencies (33), and the asymptote (34) are given in Table 3 (lines 3 to 7). The first line was taken from Table 1 in CHADDOCK'S book [2]. The different methods of plotting the observations on normal probability-paper are shown in Figure 5. The scale of the return-periods is plotted on the upper parallel to the abscissa.

Table 3--Plotting positions for ten normal observations

(1) Observation, x_m	6.7	16.7	22.5	26.8	30.0	34.0	38.7	44.0	51.3	65.1
(2) Rank, m	1	2	3	4	5	6	7	8	9	10
(3) Obs'd frequency, (m/n)	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	. . .
(4) Obs'd frequency, [(m - 1)/n]	. . . .	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
(5) Compromise [(m - 1/2)/n]	0.050	0.150	0.250	0.350	0.450	0.550	0.650	0.750	0.850	0.950
(6) Adjusted frequency (33)	0.078	0.172	0.265	0.359	0.453	0.547	0.641	0.735	0.828	0.922
(7) Asymptote (34)	0.100	0.189	0.278	0.367	0.456	0.544	0.633	0.722	0.811	0.900

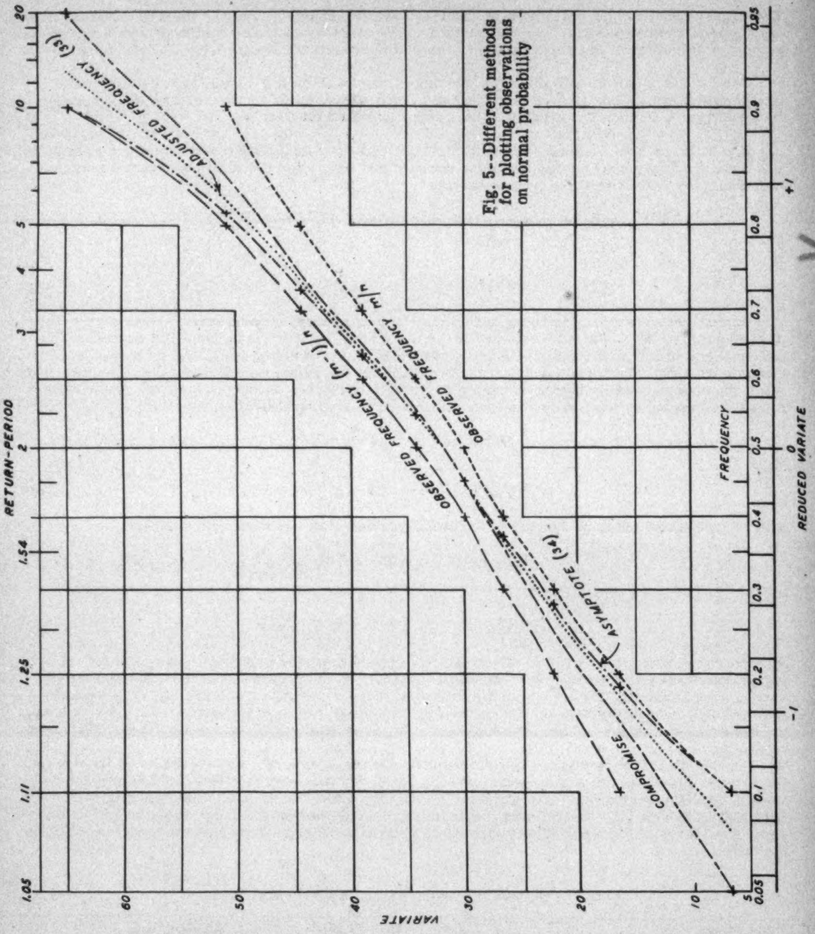

Fig. 5--Different methods for plotting observations on normal probability

From Table 3 we calculate the exceedance-intervals, the recurrence-intervals, the compromise (31′), the adjusted return-periods (33′), and the asymptotic return-periods (35). Figure 6 shows in a schematic way the return-periods as a function of the rank m. The general features of the five curves in Figures 5 and 6 have already been discussed in the text. The occurrence-interval $T(\tilde{x}_n)$ of the mode is 12.85, whereas the asymptotic value is ten, the occurrence-interval $T(\breve{x}_n)$ of the median is 14.93, the occurrence-interval $T(\bar{x}_n)$ of the mean obtained from TIPPETT'S table [10] is 16.14, and the compromise value is 20.

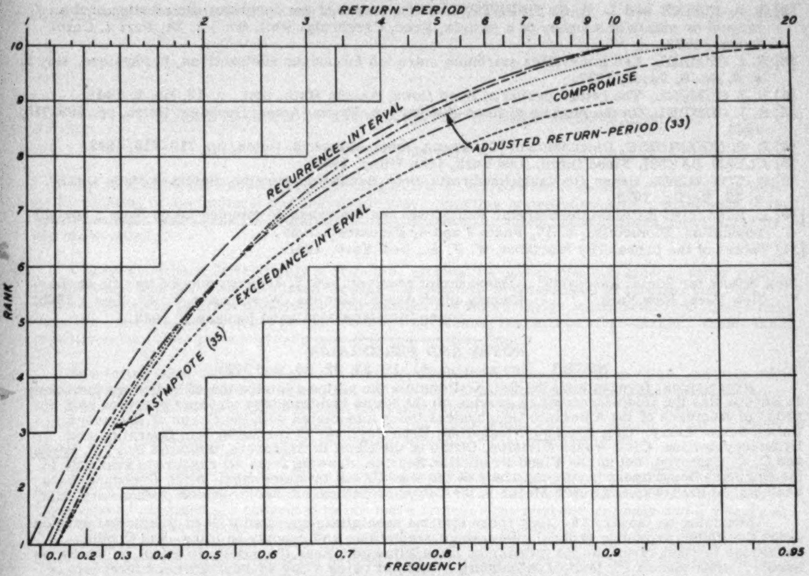

Fig. 6--Return-periods as function of rank m

Conclusions--The observed return-period of a value equal to, or larger than, the largest among n observations, called the occurrence-interval, is a function of n, and ought to be calculated from the most probable largest value, that is, from the formulas (7) and (8). For the usual distributions, the occurrence-interval $T(\tilde{x}_n)$ converges toward n. This would not hold if we determine the occurrence-interval from the median or from the mean of the largest value. Condition (12) decides whether, with increasing n, the occurrence-interval decreases or increases toward the number of observations.

The adjusted frequencies $F(\hat{x}_m)$ of the m'th observation are obtained by linear interpolation between the probability $F(\tilde{x}_1)$ of the most probable smallest observation and the probability $F(\tilde{x}_n)$ of the most probable largest observation. This method, formula (30), leads to one, and only one, series of observations to be plotted on probability-paper and eliminates the use of the exceedance- and recurrence-intervals.

The adjusted frequencies and return-periods for the floods are obtained from Table 1 and equation (30). The adjusted frequencies and return-periods for normal observations are obtained from Table 2 and equations (30′) and (32). If the number of observations is at least 100, it is sufficient to use the asymptotic formulas (34) and (35).

Acknowledgment--The investigation reported upon above was done with the support of a grant from the American Philosophical Society.

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NOTES AND PERSONALIA

NOTES (See also pp. 11, 12, 27, 32, 36, and 128)

Hydrological forecasts on the Rhine--Possibly the major contribution of hydrology to victory in Europe was the flood-forecasging service on the Rhine and tributary streams provided by a group of Members of the American Geophysical Union associated with the Corps of Engineers, United States Army. Gail Hathaway, long-time Head Engineer of the Reservoir Operation and Hydrology Section, Civil Works Division, Office of the Chief of Engineers, assisted by F. F. Snyder and D. C. Cameron, set up the Flood Prediction Service, drawing from all resources available to the Engineer Department in its long study of the world's major waterways. A. L. Cochrane, once assistant to Hathaway and now a Major in the Corps of Engineers, had prepared preliminary data.

Beginning on January 10, 1945, these civilian specialists operated a flood-prediction service along the Rhine, providing general river-stage predictions and reports on icing- and flooding-conditions for that river and its tributaries from Nijmegen, near the mouth, to Basel, at the Swiss border. After March 16, Radio Luxembourg broadcast twice a day 48-hour advance forecasts of river-stages to all Army, Corps, and Division commands conducting the offensive across the Rhine.

How important this Service was in the recent operations may be gathered from the introduction to its Bulletin. This report says: "The use of various types of amphibious equipment, floating craft, pontoon bridging, cable ferries, and temporary fixed bridges in the crossing of the Rhine will require special precautions to be taken during floods to minimize interruption of service and avoid loss of equipment. Immediately preceding and after initial crossing operations, reliable predictions of stages along reaches of the river involved will be vital to security of the crossing."

Forecasts of stream-flow from snow-surveys--The American Geophysical Union has recently received several publications giving seasonal forecasts of stream-flow from melting snow in the western mountains. Among these are: "Federal State cooperative snow surveys and irrigation water forecasts for Utah, April 1, 1945," by Utah Agricultural Experiment Station and Division of Irrigation, Soil Conservation Service, United States Department of Agriculture, in cooperation with United States Forest Service, United States Geological Survey, United States Park Service, United States Weather Bureau, and Utah State Engineer; "Seasonal water supply forecasts, Columbia River System, 1944-45 water year, April 1, 1945," by the Weather Bureau of the United States Department of Commerce.

The United States Weather Bureau makes forecasts for other snow-fed river-systems at various times each year. Utah is only one of several western States participating in the cooperative snow-survey program. The Canadian Department of Lands, Water Rights Branch, prepares forecasts for Canadian streams [see such a report on pp. -] and Canadian and United States agencies cooperate in areas of mutual interest.

A forecast for several months in advance is possible because of the lag between seasonal accumulation of snow, and its melting and subsequent discharge. The volume of accumulated snow, measured in terms of water-equivalent, is highly correlated with the volume of subsequent stream-flow and with the seasonal peak in many mountain basins. One method of determining the volume of snow is by snow-surveying--actual field-sampling by weighing snow-cores at selected stations. The Weather Bureau uses ingenious correlation between precipitation, temperature, and other factors based on the long period of record of its regular observations.

The program is well known to many hydrologists and progress in this field has been reported previously in the *Transactions*. It is mentioned here because of its interest to other geophysicists.

Transactions, American Geophysical Union Volume 26, Part I August, 1945

THE DYNAMICS OF LIQUID WATER IN DEEP SNOW-PACKS

R. W. Gerdel

Any solution of the snow-melt problem which will improve the forecasting of floods as well as forecasting of agricultural and industrial water-supplies is dependent upon a knowledge of the hydromechanic and dynamic potentials which influence the retention and discharge of water by the snow-mantle.

A deep snow-pack is relatively permeable. During the spring melting-season, water from the melting-snow surface percolates through the pack and is discharged to streams and reservoirs by overland paths or flow in the soil beneath the snow. Under some conditions, heavy rain upon the snow-blanket may not be reflected by appreciable changes in river-stages. Under other conditions rain upon the snow-pack may produce serious floods.

New fallen snow usually consists of feather, dihexagonal-dipyramidal crystals and may vary between seven and 20 per cent in density. In the high Sierra, a single storm may produce four to six feet of new snow. In a single season the summation of measured snowfall may amount to 350 inches. However, as a result of rapid settling and compaction, with a resultant density of 35 to 40 per cent, the residual snow-mantle seldom exceeds 15 feet in depth.

Before melt-water may discharge from the mantle of snow a maturing or ripening process must take place. During this process, the snow-pack becomes isothermal, the characteristic "new-snow" crystals are converted to the more typical hexagonal ice-crystals and a density of 45 to 55 per cent is usually attained. The structure of the surface of a ripe snow-pack varies with changes in climatic and meteorological conditions. During periods of high temperatures a loose, coarsely crystalline condition prevails. When temperatures drop below freezing these crystals are consolidated into crusts from a fraction to several inches in thickness. Below the surface few inches the matrix of a ripe pack appears to consist of relatively uniform oriented crystals with considerable interfacial contact. Occasional thin, discontinuous ice-planes may be present, probable remnants of old snow-surfaces.

The thermodynamic phenomena associated with the changes in crystal form during the ripening process have not been investigated. Observations on deep packs in the Sierra Nevada indicate that such changes may be the result of several concurrent processes. Settling and compaction, freezing of moisture included within or upon the new fallen snow-flakes, and recrystallization of downward percolating water from the melting-snow surface may all contribute to the structural changes within the maturing snow-mantle. The use of the dye, fuchsin, on apparently dry snow has produced indications of slow downward movement of water in quantities too small to be detected by calorimetric procedures. Acceleration of the ripening process appears to be associated with a rapid increase in degree-days above 32°F. Late season snowfall matures at a much more rapid rate than early season snows.

Recrystallization of water within the snow-pack can account for only a small part of the increase in density during the ripening process. Only one inch of water derived from the melting-snow surface could be refrozen in a pack nine feet deep with a mean temperature of 28.°5F and a density of 34 per cent. (Representative of the conditions in the Central Sierra in March, 1944.)

Technique used in determining the liquid water-content of the snow-pack--The calorimetric procedure used by BERNARD and WILSON [see 1 of "References" at end of paper] and MERRIAM [2] was adapted to the study of the liquid water-content of the maturing snow-pack at the Soda Springs Snow Research Laboratory in the central high Sierra. Both the quart- and pint-size wide-mouth thermos bottles were used as calorimeters. The calorimeter-constant for each bottle was determined and rechecked several times during the snow-melt season. Thermometers were also recalibrated several times. All hot water was obtained from melted clean snow since tap water with a high saline content proved to be unsatisfactory.

The thermos bottles were half-filled with boiling water and closed with a cork stopper provided with a thermometer. The bottle was rotated until the temperature remained constant and was then weighed. The calorimeters were immediately taken to the adjacent field-site where snow-samples were collected with a Mt. Rose core-sampler and introduced into the flasks. Selections of the portion of the pack to be sampled was dependent upon the physical characteristics of the crystal matrix. Usually the samples consisted of two or more cores, six inches in length, for each bottle. These cores were selected from the surface, upper central, lower central portions, and from the bottom of the pack. After placing the samples in the calorimeters they were returned to the laboratory where they were rotated until constant temperature was attained and again weighed.

Thermal quality, or conversely the percentage of free water in the snow-samples was determined by use of the equation, proposed by BERNARD and WILSON [1].

$$100\left\{\left[(I-F)(W+K)/S\right]-F\right\}/80 = \text{Per cent thermal quality}$$

where I = initial temperature of the hot water; F = final temperature of the mixture; W = weight of the hot water; S = weight of snow; K = calorimeter-constant; and 80 = latent heat of fusion of ice, in calories.

The term "thermal quality" is based upon the analogy to the standard engineering expression for the dryness or purity of steam. In the case of snow, this term expresses the dryness of the snow-pack.

Thermal-quality determinations were made on the snow-pack at the Soda Springs Laboratory several times each week, and occasionally several times during the day, from mid-March until early May. This period covered the ripening and discharge season for the snow at that location. In conjunction with the thermal-quality studies frequent snow-surveys were made on adjacent portions of the pack to determine variation in depth, density, and water-equivalent during the melting-season.

Results of studies on the thermal quality and liquid water-content of deep snow-packs in the central Sierra--Changes in density, temperature, and thermal quality of the pack during the gradual ripening of the snow-mantle between March 23 and April 26 are shown in Table 1. It is apparent that the pack reached maturity by the latter date since a thermal quality of less than 100 per cent was observed at all depths. The ripening process which had progressed to the center of the pack by April 7 was temporarily halted by a 44-inch blanket of new snow which fell between April 8 and April 20. The character of the hexagonal, oriented ice-crystals produced during the earlier ripening stage was not influenced by the new snow-blanket. Those portions of the pack which had matured, although they dried out and returned to thermal quality of 100 per cent, did not need to undergo further dynamic changes when the ripening process was again resumed.

It is apparent from the data presented in Table 1 that a thermal quality of less than 90 per cent, indicative of a free-water content of ten per cent, is seldom attained in a ripe pack. Thermal qualities of 78, 83, and 79 per cent, obtained on March 29, 31, and April 18 in the surface-layer of snow, may be associated with transient, perched water-tables within the pack. The lower portion of the pack, being at thermal quality of 100 per cent, may have been shielded by impermeable ice-planes at the time. Such planes are seldom impermeable for any extended period and are usually discontinuous in a ripe pack.

The complete maturity of the entire snow-pack appears to be indicated by an approximate density of 50 per cent and occurs following a rapid increase in degree-days above freezing. Discharge of melt-water is rapid after complete ripening of the pack. However, thermal quality did not drop below 87 per cent during the 48-hour period between May 2 and May 4 when 6.8 inches of water was discharged from a ripe pack.

Diurnal variations in ambient temperature have a marked influence on thermal quality in the entire pack, as shown by the data in Table 2. In March, previous to maturity of the pack, warm daytime temperatures only affect the surface; after the pack becomes homogeneously ripe, low night temperatures result in a lowered free-water content and increasing thermal quality at all depths within the snow, while high daytime temperatures result in increased liquid water within the pack. These phenomena appear to indicate that the larger capillaries within the crystal matrix are drained during the night when low temperatures prevent accretion of water from the melting-surface in quantities greater than the transmission-capacity of such pore-spaces.

Table 1--Thermal quality and associated data during the ripening of the snow-pack, Soda Springs, California, 1944

Item	Date													
	March			April							May			
	23	29	31	6	7	9	12	18	26	27	2	3	4	10
Thermal quality in per cent[a] between 14^{h}00^m and 17^{h}15^m														
Top	90.4	78.0	83.0	98.4	96.7	100	100	79.2	94.9	95.0	89.0	95.1	91.1	93.6
Center	100	100	100	97.5	94.9	99.0	100	100	97.4	92.2	95.4	93.0	90.3	.....
Bottom	100	100	100	100	100	100	100	99.4	99.0	97.5	87.1	97.4	89.6	85.6
Snow-pack, depth, and water-equivalent[b]														
Depth, inches	62	56	54	51	45	47	59	57	49	47	39	30	24	11
Density, pct	42.6	46.2	...	45.9	...	...	...	43.3	...	47.9	51.0	...	54.1	53.0
Water-equi., pct	26.4	25.9	...	23.5	...	...	...	24.7	...	22.5	19.9	...	13.1	5.8
Air-temperature, snow-pack temperature, and accumulated degree-days above 32°F from March 15[c]														
Maximum	50	48	56	47	48	41	38	49	45	45	60	56	65	54
Minimum	18	28	20	13	19	20	22	14	24	23	29	36	25	31
Mean	34.0	38.0	38.0	30.0	33.5	30.5	30.0	31.8	34.5	34.0	44.5	46.0	45.0	47.5
Accumulated degree-days	32.0	31.5	40.5	71.0	72.5	72.5	73.5	67.0	58.5	60.5	112.5	126.5	139.5	225.0
Temperature, center snow-pack, °F	31.4	31.6	32.0	32.0	32.0	32.0	32.0	31.9	32.0	32.0	32.0	32.0	32.0	32.0

[a] Thermal quality occasionally slightly in excess of 100 per cent but reported as 100 per cent.

[b] Forty-four inches of new snow on daily-precipitation basis between April 8 and 20; data for April 16 and May 6 instead of April 18 and May 4 as for thermal quality. [c]Snow-pack temperatures are means of central portions of pack as determined by thermocouples and deflection galvanometer.

Table 2--Effect of daily maximum and minimum temperature on the thermal quality in the snow-pack, Soda Springs, California, 1944

Portion sampled	Date and period										
	March 23		April 7		April 26		May 2	May 3		May 4	May 5
	10^{h}30^m	15^{h}30^m	10^{h}20^m	17^{h}10^m	10^{h}30^m	16^{h}30^m	17^{h}00^m	09^{h}00^m	15^{h}30^m	15^{h}30^m	08^{h}30^m
Thermal quality in per cent[a]											
Top	100	90.4	100	96.7	100	94.9	89.0	98.4	95.1	91.1	100
Center	100	100	97.5	94.9	98.7	97.4	95.4	96.9	93.0	90.3	95.3
Bottom	100	100	100	100	99.0	99.0	87.1	99.3	97.4	89.6	97.0
Maximum or minimum between observations in °F											
Maximum		50		48		45		35	56	65	. .
Minimum		. .		. .		. .		. .	. .	28	26

[a] Thermal quality reported as 100 per cent whenever in excess of that value or when temperature in the snow was less than 31.°8F except that thermal quality was always determined on the top portion.

Notes: The position sampled did not consist of fixed depths or core-lengths. Samples were taken from the "horizons" of definite physical structure. The top portion usually consisted of coarse granular crystals, loose or consolidated depending upon temperature and time of sampling; it varied from three to ten inches in depth. The bottom, varying from two to 14 inches in thickness, was a compact, coarse crystalline matrix stratified with ice-layers up to one inch thick. The center varied from a moderately compact snow-crystal to a matrix of compact coarse crystals with frequent thin ice-layers as the season progressed. Efforts were made to obtain representative aliquots from each horizon. Each sample consisted of portions from at least three cores.

CHURCH [5] refers to an "overripeness" and "superdensity" of the snow-pack which is probably indicative of a water-content in excess of the capillary capacity. The conditions to which he refers are probably associated with the diurnal variation in free-water content of a ripe pack.

That the change in water-content of a snow-pack during periods of low temperature is actually a drainage of free water and not the freezing of water within the mantle is shown in Table 3. At 15^h30^m on May 4, when melting of the snow-surface appeared to have ceased for the day, the water-equivalent of the snow-pack was determined to be 14.78 inches and the average thermal quality 90.3 per cent. The following morning, after a nighttime low of 26°F, the water-equivalent of the pack was only 13.78 inches and the thermal quality 97.4 per cent. The one inch of water lost from the pack as determined by measurements of depth and density agrees closely with the 1.05 inches of loss calculated from the differences in thermal quality.

Table 3--Capillary and surface tension in the ripe snow-pack, Soda Springs, California, 1944

Date	May 4, 1944		May 5, 1944
Time	15^h30^m		08^h30^m
Pack-depth, inches	28		26
Pack-density, pct.	52.8		53.0
Water-equivalent, inches	14.78		13.78
Temperature, at time sampling	65.0		. . .
During previous night, °F	. . .		26.0
Thermal quality, pct, for portion sampled			
Top six inches	91.1		100.0
Middle eight inches	90.3		95.3
Bottom 12 inches	89.6		97.0
Average	90.3		97.4
Difference		7.1	

Notes: Thermal-quality difference is equivalent to 1.05 inches of the 14.78 inches of water-equivalent in the snow-pack at 15^h30^m, May 4, 1944; (14.78 - 1.05) = 13.73 inches water-equivalent theoretically remaining -- compare with 13.78 inches water-equivalent at 08h30m, May 5, 1944. It is apparent that drainage took place all night and the combined surface and capillary tension of the snow-pack is sufficient to hold only 2.6 per cent of the water by weight of snow.

There is little evidence to indicate that any appreciable amount of the liquid water in the ripe snow-pack is affected by thermal transfer either as vapor or by capillary tension from the warm, moist portions of the pack to the upper, colder and dryer portions during short periods of below-freezing temperatures. The frozen crust, commonly present during the night, is usually very thin and frequently discontinuous. The total amount of liquid water solidified in the crust must be very small. The fact that such crusts are frequently only in intermittent contact with the moist portions of the pack indicates that capillary tension between the unfrozen and frozen portions has been broken. Such conditions probably also indicate that the moist portions of the pack have shrunk during the period of low temperature as a result of drainage and removal of free water.

In order to ascertain the approximate transmission-constant for liquid water through a ripe snow-pack, the thermal quality of the surface, central, and lower portions of a 30-inch deep pack was determined after surface-melting had ceased for the day. One-half inch of water at 32°F was then applied to a four-foot square area and thermal quality determined on the surface-portion as soon as the last trace of water had infiltered into the pack. Forty-five minutes later, thermal quality was again determined on the surface-portion of the snow. Plotting the data obtained from this experiment (see Fig. 1) and extending the straight-line depletion-curve to the abscissa representing the original water-content of the snow, a transmission-rate of 0.44 inch of water per foot per hour was indicated.

Using such a transmission-rate, the one inch of water discharged from the 28-inch snow-pack between 15^h30^m, May 4, and 08^h30^m, May 5, could have been drained from the pack in less than two hours.

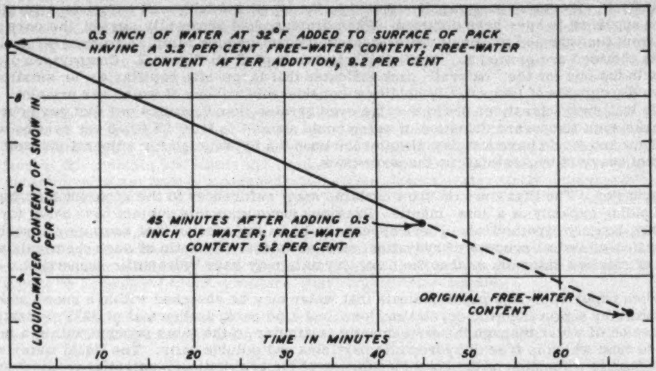

Fig. 1--Moisture-tension curves for snow and soil, Soda Springs, California, 1944

During the course of these investigations on free water in the ripe snow-mantle it became apparent that the transmission or retention of liquid water within the crystal-matrix of the pack might be analogous to the same phenomena in a soil-profile. In order to determine the possible relationship between the capillary potential of a ripe snow-mantle and of soils of different texture the liquid water-content of the pack was determined at 12, 45, 65, and 100 cm above a slowly moving water-table which extended about two inches upward from the soil-surface into the ripe pack. The liquid water-content of the snow was found to vary from 14.4 per cent at 12 cm to 8.9 per cent at 100 cm. Converting the elevations of the samples above the water-table into pF-values (the logarithm of the tension in cm of water, or in this case the logarithm of the elevation above the water-table) and plotting the data produced the pF-moisture curve designated as "natural" ripe snow-pack on Figure 2. Comparison of this pF-moisture curve for snow with one for sand presented by BAVER [4] indicates that the capillary tension in a ripe snow-pack is less than that for sand.

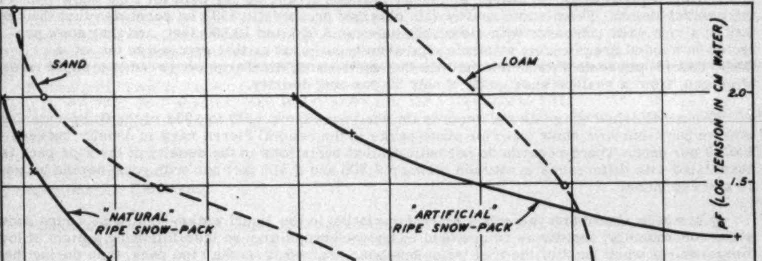

Fig. 2--Transmission-rate for water at 32°F through a ripe snow-pack of 30-inch depth, Soda Springs, California, 1944

Further studies on the probable free energy of a ripe snow were made by immersing the lower two inches of a long core (two inches by six feet) of snow, contained in a Mt. Rose sampler, in water at 32°F. Ice-water was rapidly applied to the top of the tube until complete saturation of the core appeared to have been obtained. When drainage had apparently ceased, the core was removed from the tube and the liquid water-content determined for samples from several elevations. The data obtained are plotted as "artificial" ripe snow-pack on Figure 2. Comparison of this curve with the one for the "natural" pack indicates that large-size capillaries, or small non-capillary voids, capable of temporarily holding a considerable volume of water are present. It is probable that such interstices drain at rates even greater than 0.44 inch per foot per hour. In deep packs such temporary detention of water could amount to from 25 to 50 per cent by weight of the snow and would have a material influence upon the hydrograph for adjacent streams during periods of heavy storm-rainfall on the snow-pack.

Discussion--The literature on snow contains many references to the apparent high liquid-water-holding capacity of a snow-mantle. Previous ideas upon this subject have been, for the most part, largely hypothetical. There appears to be an impression that snow may absorb water by a physico-chemical process of hydration, such as is characteristic of such chemicals as copper sulfate or calcium chloride, or that the snow-crystals may have hydrophilic properties.

Studies reported in this paper indicate that water may be absorbed within a snow-pack of low temperature by a process of recrystallization. In a ripe pack, isothermal at 32°F, retention or transmission of water through the snow-mantle is similar to the same process within a moderately coarse sand which is free of hydrophilic particles and soluble salts. The liquid water within the ripe pack is a function of the combined forces of the gravitational-potential gradient and the capillary-potential gradient. Potential equilibrium is established in accordance with the depth to the water-table which may be within the lower portion of the snow-pack, at the soil-surface, or at some depth within the underlying soil. In the latter case establishment of equilibrium within the pack will be influenced by the potential-gradient and transmission-constant for the underlying soil.

The transmission-rate and liquid-water retention-capacity of a ripe pack are probably influenced by the proportion of capillary and non-capillary voids, and therefore by variations in the density of the pack.

Considerable variation in the density of ripe snow-packs at different locations has been reported. Such variations may be due to the proportion of capillary and non-capillary voids within the crystal-matrix, or to differences in the quantity of liquid water contained in the voids at the time when snow-surveys were made.

CHURCH [5] reports variations in density between 35 and 56 per cent for ripe snow-packs in the central Sierra. From snow-survey data obtained previous to 1932 he concludes that the density of a ripe pack increases with elevations between 6,000 and 10,000 feet, and that snow protected in wooded areas rarely attains a ripe density as great as that exposed to the wind. GARSTKA [3] presents data which indicate that melt-water discharge occurred at a rapid rate, in Michigan, from a shallow snow-pack of only 35 per cent density.

The unpublished snow-survey records for the years from 1932 to 1934 of the California Cooperative Snow-Surveys show that ripe snow-packs in the central Sierra vary in density between 45 and 57 per cent. These records do not indicate that variations in the density of the ripe pack is associated with differences in altitude between 3,500 and 8,500 feet nor with pack-depths between 24 and 240 inches.

It has been shown that there is a diurnal variation in the liquid water-content of a ripe snow-pack, consequently, density as determined by snow-surveys may be less following a night of low temperatures when most of the free water has been drained from the ripe pack, than during those portions of the day when high melting-rates result in an accumulation of liquid water in the larger voids within the snow-mantle. The association of pack-density with ripeness is further complicated by the possible accumulation of a layer of new, unripe snow upon the surface of a mature pack just previous to the snow-survey. The snow-surveyor assumes that a pack is mature or ripe when discharge of melt-water is observable. However, discharge may take place in appreciable quantities as a result of "edge-melting" for several weeks before the major portion of the pack has ripened. Such "edge-melting" occurs where boulders, stumps, and other heat-absorbing structures are exposed above, or near the surface of the pack.

Further studies are necessary to establish any relationship between the total-solids density of a ripe pack and such factors as climate, cover, topography, altitude, and exposure. It is also essential that the capillary and non-capillary porosity- and transmission-constants be determined for ripe packs of different depths and apparent different densities. Such information, which might be obtained by a combination of snow-surveys and simplified calorimetric procedures, would permit improvement in the analysis of the effect of storm-rainfall and high melting-rates on streamflow.

Conclusions--(1) An immature snow-pack may retain water from storm-rainfall or rapid surface-melt by several physical processes. Among these are: (a) The capacity of the pack to absorb the latent heat of fusion of the free water with resultant crystallization; (b) adsorption upon the surface of the crystals and within the capillary and non-capillary voids of the crystal-matrix; and (c) retention of water within a perched water-table above a temporarily impermeable ice-plane within the pack.

(2) A mature snow-pack, having an homogeneous, oriented crystal-structure appears to retain storm-rainfall or snow-melt water by capillary tension only, although a considerable amount of water may be temporarily retained in the larger voids. Neither hydration nor hydrophilic properties appear to be present within a mature, discharging snow-mantle.

(3) The pF-concept as applied to soil-moisture appears to be satisfactory as a means of evaluating the water-holding capacity and percolation-rate of a ripe snow-pack.

(4) The capillary tension within a 30-inch deep ripe snow-pack appears to be insufficient to support a liquid water-content much greater than ten per cent by weight or five per cent by volume of the snow.

(5) The transmission-rate for water through a mature snow-pack was determined, from a single experiment, to be approximately 0.44 inch per foot per hour.

(6) Variations in the diurnal march of temperature, humidity, and wind-velocity in different portions of the country may have sufficient effect upon the structure of a ripe snow-pack to influence the retention and discharge of water from storm-rainfall and snow-melt.

Acknowledgment--The writer wishes to express his appreciation to FRED PAGET, Division of Water Resources, State of California, for permission to examine the snow-survey records of the California Cooperative Snow-Surveys.

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DISCUSSION

Note by Author--Since the preparation of this paper, more data have been collected which substantiate previous observations on the low water-holding capacity of mature, deep snow-packs.

The use of improved technique and of apparatus specifically designed for the studies on the hydrodynamics of discharging snow-packs adds emphasis to the results of these later experiments.

Studies have been made on ripe and pre-ripe snow-packs which varied in depth between 42 and 115 inches and between 35 and 52 per cent in density. Sample sites included wooded areas, open meadows and wind-swept packs at high altitudes.

For seven samples, the water-holding capacity varied between 2.8 and 9.3 per cent. Based upon the density of the samples these values represent a capacity of 0.14 to 0.42 inches of free water per foot of dry snow.

A capacity of 0.80 inch of water per foot of snow was obtained for one sample from a 42-inch pack of 50 per cent density. Since these experiments were designed primarily to test apparatus and develop technique, it is probable that this particular sample was not given sufficient time after addition of free water to reach equilibrium with the surrounding pack.

Further studies by means of calorimetric procedures showed that a pack which contained 8.2 per cent free water at noon on April 25, contained only 2.6 per cent free-water content by noon of April 26. A six-inch blanket of new snow which fell during the intervening period provided insulation, which retarded melting and permitted free drainage of the liquid water from the pack. Drainage-rates have been observed which varied between 0.5 and 2.5 inches per foot per hour. This large variation appears to be associated with the frequency and permeability of ice-planes within the snow-pack. It is probable that such variations are less common in extensive snow-packs where ice-planes are usually discontinuous than in small samples (8 in × 25 in cores) used in these studies.

During a rain storm on a residual snow-pack of 15 inches depth and 50 per cent density, free water was observed to be dripping from the bottom of the pack where it was arched above the soil-surface. The free-water content of this saturated pack was found to vary between 4.4 and 7.7 per cent, equivalent to 0.2 to 0.4 inch of water per foot of snow.

Further analyses of data are being made and the technique and apparatus used in these studies will be presented in a paper now in preparation.

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

(See also pp. 18, 58, 68, and 126)

Comité National Français de Géodesie et Géophysique, Section d'Hydrologie Scientifique: Instructions hydrologiques. 96 pp., 8 vo., Paris, 1940.

This booklet, which summarizes succinctly the field-methods of making a wide range of hydrologic measurements, is the work of a Committee of five French hydrologists. Instructions and specifications are given for measuring precipitation, evaporation from free water-surface, and atmospheric humidity. There is a section on quality of water that includes measurements of water-temperatures (rivers, lakes, springs, and wells), conductivity, pH, hydrometry, and turbidity. Ground-water is represented by a short discussion of currents and movement, measurements of depth of a well, of recording water-levels, and measuring well-discharges. Instructions are also given for measuring discharge of springs and small water-courses.

The instructions concerning observations for the study of the flow of rivers is extremely terse, giving only a few notes on direction of flow, use of the current-meter recording, pulsations, and the aspect of the free surface. Measurement of currents in lakes and reservoirs is treated even more briefly and a few suggested forms for use in entering notes in the field completes this useful report.

The booklet compresses considerable practical information into a few pages and its small size facilitates and encourages use in the field. When it is considered that the booklet was published during the military occupation of France, one is impressed with the enterprise of the French hydrologists.

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Transactions, American Geophysical Union Volume 26, Part I August, 1945

PERMEABILITY OF FIVE WESTERN SOILS AS AFFECTED BY THE PERCENTAGE OF SODIUM OF THE IRRIGATION-WATER

Milton Fireman and O. C. Magistad

(Contribution from the U. S. Regional Salinity Laboratory, Riverside, California, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture, in cooperation with the eleven western States and the Territory of Hawaii)

Abstract--Data are presented for five western soils showing their permeability to Riverside tap-water after preliminary leaching with waters of various percentages of sodium. Although the tendency for high-sodium water to reduce soil-permeability has been known qualitatively for many years, few data are available to indicate the magnitude of the change that occurs.

The data indicate: (1) There is no sharp break in the permeability-curves as the percentage of sodium in the waters is increased. (2) Permeability decreases greatly when the salt-concentration is reduced following percolation with high-sodium water. (3) Other factors also greatly modify permeabilities, that is, all soils do not act alike. (4) Under field-conditions it is the absolute permeability which governs soil use and productivity. Since soils react differently to the same water, it is incorrect to give a precise percentage of sodium above which irrigation-waters will cause trouble in this respect. Indicating a range of percentages would seem to be preferable practice. (5) Soils high in organic matter have higher permeabilities than normal soils when irrigated with waters of low-sodium percentage, and vice versa with waters of high-sodium percentages.

A factor which has received considerable attention in soil-reclamation, but which is often overlooked in studies of permeability and infiltration, is the chemical composition of the water used. Some alkali soils are hundreds of times more permeable to a "hard" irrigation-water than they are to distilled or rain-water, or to low-salt waters containing a high percentage of sodium. Calcium is the principal absorbed cation of the collidal complex of most agricultural soils. In general, these soils are reasonably permeable to water and have a favorable physical condition for cultivation and crop-production. When water containing a high percentage of sodium salts comes into contact with or is percolated through these soils, base exchange takes place and sodium ions replace a considerable portion of the absorbed calcium ions. Some soils remain moderately permeable when leached with high-sodium water as long as the salt-content remains fairly high because the presence of the salt tends to keep the soils flocculated. If the high-sodium water is followed by a water of considerably lower salt-concentration, the soil will disperse immediately and become sticky and relatively impermeable, regardless of the chemical composition of the latter irrigation-water [see 1 of "References" at end of paper].

According to SCOFIELD and HEADLEY [2], "when irrigation-water contains more sodium and potassium than calcium and magnesium, there is danger that its continued use may cause the land to become hard and impermeable to water."

According to EATON [3], "Waters carrying sodium to the extent of 65 per cent of the total bases are looked upon as being of doubtful quality, waters with less than 50 per cent as being wholly satisfactory in this regard, and those with more than 65 per cent of sodium, as presenting a progressively greater hazard as the percentage-increases."

KELLEY, et al [4], have written, "Despite the fact that very little sodium is absorbed from saline solutions in which the ratio of sodium to calcium is not greater than 2:1, it does not follow that the application of a comparatively dilute saline irrigation-water containing sodium and calcium + magnesium in the ratio of 2:1 will have no deleterious effect on the soil."

The present study was undertaken to clarify our knowledge of some of the factors which influence infiltration, but more particularly to delimit if possible the effects of the chemical composition of the irrigation-water on soil-permeability. Fifteen 200-gram air-dry samples of each of five western soils were packed as described elsewhere [5] into permeameters. The 15 samples of

each soil were divided into five sets of three each and each set was leached with approximately 24 surface inches of a water containing a total of 25 equivalents per million (epm) of salt (approximately 1,400 ppm) but having different percentages of sodium salts, namely 50, 75, 85, 90, and 96 per cent. The leachate was withdrawn and measured at intervals and the permeability calculated in inches per hour per unit potential-gradient. At the conclusion of this treatment the saline waters were replaced by Riverside tap-water, which contains approximately 280 ppm of salts of which approximately 45 per cent are sodium salts. Leaching was continued (and permeabilities were calculated) until 24 inches of tap-water had passed through each sample, or for a period of three weeks, whichever was shorter.

Some of the chemical and physical characteristics of the soils used in this study are given in Table 1.

Table 1--Characteristics of soils used

Lab. No.	Soil series and type	Location	pH	Remarks
60	Aiken clay loam	Paradise, California	5.9	Kaolinitic
85	Reagan clay loam	Roswell, New Mexico	7.8	Calcareous and gypsiferous
376	Hanford sandy loam[a]	Riverside, California	7.6	Calcareous and high in organic matter
79	Cajon silty clay loam[b]	Glendale, Arizona	7.7	Calcareous
247	Altamont clay loam	Los Angeles, California	6.2	High in organic matter

[a] Although this sample was mapped as Hanford sandy loam, Hanford soils by definition are non-calcareous; the correct series designation is not known. [b] F. O. Youngs, Regional Inspector, Division of Soil Surveys, informed us in a recent communication that this soil is now called Glendale silty clay loam.

Curves obtained by plotting the final permeability to tap-water against the per cent of sodium salts in the original leaching water are given in Figure 1.

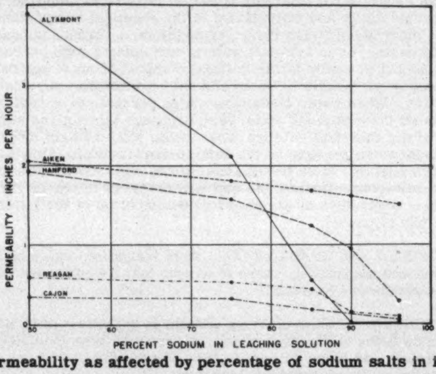

Fig. 1--Soil-permeability as affected by percentage of sodium salts in irrigation-water

It is recognized that somewhat different results would have been obtained with different initial and final water-treatments. However, the principles involved would be identical and the curves obtained more or less similar.

Although the exact relationship between response in the field and behavior in the laboratory is not known, results obtained in the laboratory are qualitatively in agreement with results in the field, are usually quickly and inexpensively obtained, and are very useful in practical consideration of problems involving low permeability resulting from high-sodium waters. Laboratory-tests are especially useful in predicting the general trend that will occur in field-permeability upon changing irrigation-waters, for example, what will happen when a water relatively high in salts containing a large percentage of sodium is followed by rain water or a water low in salts.

Examination of Figure 1 discloses several important relationships which hold for the group of soils examined.

(1) There is no sharp break in any of the curves in which permeability is plotted against the percentage of sodium salts in the initial water-treatment. This indicates that there is no critical percentage of sodium in irrigation-waters below which no deleterious effects may be expected, and above which considerable deleterious effects may be expected.

(2) All soils do not respond alike to increasingly great percentages of sodium in the irrigation-water. For example, the ratio of the final permeabilities to tap-water, of the samples treated initially with waters containing 50 and 96 per cent sodium salts (25 epm) respectively, was 1.4:1 for the Aiken clay-loam and 8,300:1 for the Altamont clay-loam. The slope of the permeability-curve is a complex function of many additional factors. Among the most important of these are soil-texture, mineralogical composition, previous history (or structure), organic matter, gypsum content, lime content, and the type of bases on the exchange complex. These factors have been discussed more or less adequately by a number of workers [1, 6, 7]. Lime and gypsum and other soluble soil-minerals are beneficial in tending to maintain soil-permeability as in the case of the Hanford, Reagan, and Cajon soils (see Fig. 1), in that they contribute appreciable amounts of calcium to the percolating water and so lower the percentage of sodium and increase the salt-content (which tends to aid flocculation).

(3) The permeability of all soils decreased when the water was changed from water containing 1,400 ppm of 50, 75, 85, 90, or 96 per cent sodium salts to Riverside tap-water containing 280 ppm, approximately 45 per cent sodium; this despite the fact that the Riverside water was a "better" water than the first, emphasizing again [8] the fact that so-called reclamation must involve physical as well as chemical changes. It is important that soil be allowed to dry in order for the favorable physical changes to take place to any extent [8].

(4) Irrigating a soil with a water of high percentage of sodium usually leads to a decrease in permeability. An even more pronounced effect is obtained when a water low in salts (irrigation- or rain-water) follows irrigation with water of high salt-concentration, especially if the latter waters are high in sodium. The absolute decrease in permeability is more important than the percentage-increase. That is, the practices employed and the economics involved might be such that a decrease of 25 per cent in permeability might be extremely serious in one area, while in another, a decrease of 50 or 60 per cent in permeability might conceivably be welcomed. From Figure 1, it can be seen that the permeability of the Altamont clay-loam decreases from 3.9 inches per hour if the salts are 50 per cent sodium to 0.55 inch per hour if the salts are 85 per cent sodium, yet this latter permeability-value is higher than any obtained for the Cajon soil.

(5) The behavior of the Altamont clay-loam is unique. This soil, in spite of its high clay-content, normally has a very high permeability. This is attributed to its high content of organic matter and excellent structure. With waters low in salts following leaching with water high in percentage of sodium, the soil has an extremely low permeability, considerably lower than the other two clay-loams, the Aiken and Reagan. This behavior of organic matter--rich soils being associated with high permeability at low percentages of sodium and very low permeabilities at high levels of sodium--is in accord with the theories of ANTIPOV-KARATAEV, et al [9]. These workers, when classifying alkali soils on the basis of replaceable sodium status, take organic-matter content into consideration.

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RELATIONS OF LAMELLAE AND CRYSTALLOGRAPHY OF QUARTZ AND FABRIC DIRECTIONS IN SOME DEFORMED ROCKS

Earl Ingerson and O. F. Tuttle

Abstract--Deformation lamellae in quartz are described in detail. Statistical studies confirm previously described relationships. Detailed measurements in separate zones of the petrofabric diagrams yield new data on the nature of the lamellae and their control. The uses of the lamellae in geologic interpretation are outlined.

Introduction

Description of deformation-lamellae--The quartz lamellae discussed below are parallel planar structures in the quartz grains of deformed rocks. They are elusive structures that in thin section can be seen only when they are nearly parallel to the axis of the microscope. It has been found that sections cut two or three times standard thickness greatly facilitate their recognition. Diminishing the light with the substage diaphragm and turning the lamellae parallel to the vibration plane of the lower nicol also help to make them more distinct.

The BECKE line moves toward the lamellae as the tube of the microscope is raised, which indicates a higher index. The lamellae have a slightly bluish tinge against the rest of the grain, which appears very slightly pink, also indicating a higher index for the lamellae. This does not check the observations of GRIGGS and BELL [see 1 of "References" at end of paper] and of FAIRBAIRN [2] who thought that the lamellae showed slightly lower index.

Much confusion has resulted from the descriptions of lamellae in the literature. This is due in part to the inherent difficulties in description, but is probably more largely due to the great variability of the lamellae. They have been found to vary greatly in character in different localities and rock-types. All lamellae show a difference in index of refraction between each lamella and the surrounding part of the quartz grain. Many sets, however, also have a plane of brownish material between each two lamellae. In some cases this brownish material can be resolved at high magnification into minute inclusions, and some can be identified as liquid inclusions. In general, the character of the material between the lamellae cannot be resolved. A third type of "lamellae" should be called "relict" lamellae because the difference in index of refraction is no longer discernible. Apparently the original lamellae have recrystallized, leaving the brownish material that was originally between the individual lamellae.

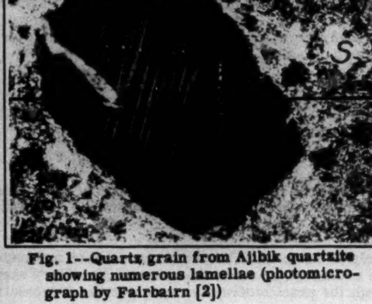

Fig. 1--Quartz grain from Ajibik quartzite showing numerous lamellae (photomicrograph by Fairbairn [2])

Deformation-lamellae (Fig. 1) are not to be confused with cleavage, fractures, planes of liquid inclusions, or other structures in quartz grains. They are not definite breaks in the quartz grains as are cleavage and fracture planes. They are more regular than planes of liquid inclusions, do not contain discrete particles, and are confined to individual grains. Planes of liquid inclusions, on the other hand, commonly cross many quartz grains without breaks or offsets, especially in metamorphic rocks. Deformation-lamellae in quartz are not sharp, straight bands like twin lamellae in plagioclase, for example, but they are sufficiently near to being plane and parallel so that the orientation of a whole set of them can be determined at once by a single setting on the universal stage. They are commonly slightly lens-shaped and some or all of them in a grain may pinch out entirely before they reach the edge of the grain. They may be more or less uniformly distributed over a whole grain, as in the illustration, but there are all gradations between such grains and those which have no lamellae at all. In other words, a grain may have a few lamellae in any position, or may have groups of them in two or more positions. In the latter case, the lamellae in all groups are parallel, except in the comparatively rare grains that show two or more sets of lamellae. Deformation-lamellae commonly form transverse to the length of grains.

Deformation-lamellae are moderately common in deformed rocks that have not been recrystallized. They are rarely mentioned in descriptions of such rocks, however, apparently because they are seldom seen. They show a high degree of preferred orientation and cannot be seen unless they stand at a high angle to the thin section. In order for them to be seen at all, therefore, the thin section must be cut in a proper orientation. Even with the most favorable orientation of the thin section it is quite difficult to observe the lamellae in the average rock. Only a very small percentage of the grains show them and most of the grains that do so are by no means covered with them.

Historical summary--The early work on lamellae in quartz was largely descriptive, but some of the investigators attempted explanations of them. In 1878, KALKOWSKY [3, p. 26] described in quartz grains of a gneiss, striations that showed slightly different interference colors for some positions of the grains. This is certainly a property of many deformation-lamellae. KALKOWSKY did not state whether the striations could be seen without crossed nicols. He believed the striations to be parallel to the c-axis, but the only evidence cited was that grains with low interference colors did not show them. As indicated below, however, quite a different relation appears to obtain in general. KALKOWSKY thought the cause of the lamellae to be the same as that of undulatory extinction--slight differences of optical orientation--but did not say how the differences are produced.

In 1883, BÖHM [4] described striations in quartz grains in several different kinds of metamorphic rocks. His work is much more widely known than KALKOWSKY'S, and for many years deformation-lamellae in quartz have been generally known as "BÖHM lamellae." Some of the structures that he described were undoubtedly planes of liquid inclusions. In others, however, inclusions were not resolved even with an oil-immersion lens and it is probable that these were true deformation-lamellae, although BÖHM thought that they were planes of liquid inclusions of ultramicroscopic size. Because of the uncertainty, it is probably better to use the term "deformation-lamellae" rather than "BÖHM lamellae" for these structures that are confined to deformed rocks and do not contain liquid inclusions.

BECKE [5] and MÜGGE [6] both observed that the planes of deformation commonly are within 30° of the base. BECKE thought them to be healed fractures. MÜGGE interpreted them as translation-gliding planes but did not assign definite indices to them because of the variability in orientation with respect to the c-axis.

SANDER [7] was the first to make a statistical study of deformation-lamellae in quartz. He found the angle between the normal of the lamellae and the c-axis to vary from 6° to 30° with more showing an angle of 22° than any other value. From this he concluded that the lamellae are the traces of translation-gliding planes that form an angle of about 22° with the base.

FAIRBAIRN [2] made a more detailed study in which he found the angle to vary from 3° to 85° with maxima at 18° and 27°. Because of this variability, FAIRBAIRN explained the lamellae as due to the functioning of a glide-line [m:r], rather than one or more glide-planes. According to this view, because of the compactness of the structure of quartz, gliding can take place on any plane that contains the glide-line [m:r].

Present status of the problem of quartz deformation--Evidence is accumulating that quartz has been plastically deformed in nature:

(1) Some quartz grains are bent between grains of other minerals (see SANDER [7], Fig. 66).

(2) Almost all metamorphic rocks show a higher degree of preferred orientation of the c-axes of quartz than do the igneous or sedimentary rocks like those from which the metamorphic ones were derived.

(3) The lamellae under consideration occur only in unrecrystallized deformed rocks and show a much stronger preferred orientation than do the c-axes of quartz in the same rocks. They almost certainly record the deformation of quartz, although the exact mechanism by which the deformation takes place is not yet entirely clear.

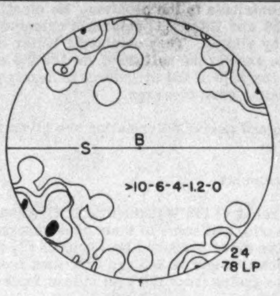
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Fig. 2

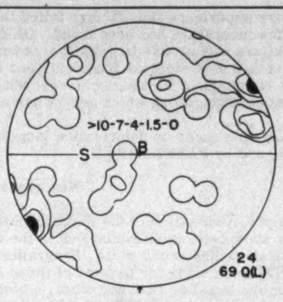
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Fig. 3

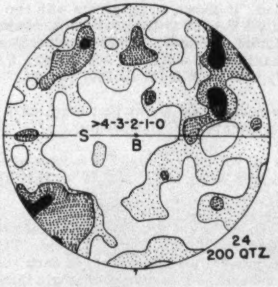
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Fig. 4

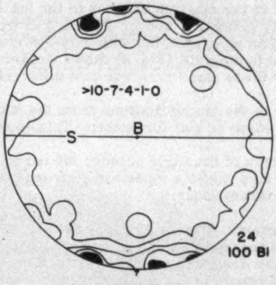
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Fig. 5

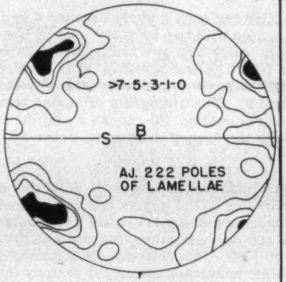
>7-5-3-1-0
S
B
AJ. 222 POLES
OF LAMELLAE

Fig. 6

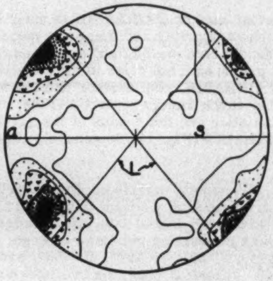

Fig. 7

Fig. 2--Diagram of poles of quartz deformation lamellae from a biotite gneiss collected just east of Rock Creek, two miles north of District of Columbia-Maryland Line
Fig. 3--Diagram prepared from c-axes of quartz grains whose lamellae are plotted in Fig. 2
Fig. 4--Non-selective quartz diagram (c-axes) from biotite gneiss of Figs. 2 and 3
Fig. 5--Biotite diagram from biotite gneiss of Figs. 2-4
Fig. 6--Diagram of lamellae from Ajibik quartzite (compare Fig. 7)
Fig. 7--Fairbairn's diagram of lamellae from Ajibik quartzite (compare Fig. 6)

Laboratory experience thus far has failed to contribute to the problem. No plastic deformation of quartz in the laboratory has been found. GRIGGS and BELL [1] deformed oriented cylinders of quartz, but failure was always by fracture, never by gliding. They obtained a better correlation between the orientation of elongate fragments and the axes of the cylinders used in the experiments than with the structure of the quartz, except when the axis of the cylinder was nearly parallel to the unit rhombohedron, along which quartz has a fairly good cleavage.

Additional references on deformation lamellae and quartz deformation are given by GRIGGS and BELL [1] and by FAIRBAIRN [2].

New measurements

Microscopic examination of the metamorphic rocks of the Washington, D. C. Area reveals that most of them show deformation-lamellae in the quartz, and some of them have enough lamellae to make statistical studies worth while. Diagrams like those prepared by SANDER [7] and by FAIRBAIRN [2] were made for several of these rocks. Figures 2-5 are diagrams from the rock that showed more lamellae than any other, a biotite gneiss from the east side of Rock Creek, about two miles north of where it crosses the District Line.

Figure 2 is the diagram of poles to the lamellae. It shows an ac-girdle with two sharp maxima about half way between a and c. Figure 3 is from the c-axes of the grains that showed lamellae. It also shows an ac-girdle, but with only one maximum, and more points near the B-axis. The non-selective quartz diagram (Fig. 4) shows weaker maxima and a further scattering. FAIRBAIRN found exactly these same relations in a different type of rock from another region.

Figure 5 is the biotite diagram from the same section and shows that the B-axis of the mica fabric is the same as that for quartz. This is not a necessary relationship.

A histogram of the angle between the normals to the lamellae and the c-axes of the corresponding quartz grains shows a moderately strong maximum between 10° and 20°. This also agrees with all previous observations.

Measurements on many grains, however, were at variance with the statistical results. There are enough of these variations to make it imperative to find the reason for them. This can be done by breaking the diagrams up into zones and making careful measurements in each zone, but in the rocks of the District of Columbia Area there are not enough lamellae in a single thin section to make such a detailed zonal study very impressive.

The material used by FAIRBAIRN is much better for such a study because a greater percentage of the grains show lamellae and there are more grains with two or more sets of lamellae. FAIRBAIRN very kindly furnished a hand specimen from which new ac- and bc-sections were prepared. The diagram prepared from poles to all lamellae in the ac-section (Fig. 6) is identical with that obtained by FAIRBAIRN from another section with the same orientation (Fig. 7). The diagrams of the c-axes also check almost perfectly (Figs. 8 and 9). The histogram of angles between the normals to the lamellae and the c-axes of the quartz grains (Fig. 10) checks a similar histogram prepared by FAIRBAIRN (Fig. 11), in general, although the second maximum, below 20°, is not pronounced.

Thus far, the results merely confirm previous findings. If, however, selective diagrams are prepared by dividing each diagram into zones according to the angles that the c-axes of the quartz grains make with the B fabric axis, and detailed measurements are made and tabulated for each zone, some very interesting relations emerge. Each non-selective diagram was divided into four zones with $c \wedge \underline{B}$ = 0°-30°, 30°-50°, 50°-70°, and 70°-90°, respectively. The innermost zone is thus a solid 60° spherical cone, the two intermediate zones are spherical sectors (hollow cones-in-cone) and the outer zone is bounded above by the median plane of the projection sphere and below by a hollow 140° cone.

Only two of these selective diagrams are reproduced (Figs. 12 and 13), because the data are more effectively illustrated in tabular form. In these two diagrams some of the points have been omitted so that the others will show up more clearly.

Measurements--In each zone the angle between normal to the lamellae and the c-axis of the grain containing them was measured for each set of lamellae. This was done by placing the point representing the pole to the lamellae and that representing the c-axis of the grain above a great circle of the net and reading the angle between the two points.

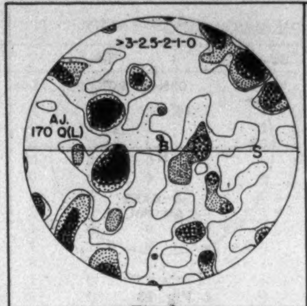

Fig. 8

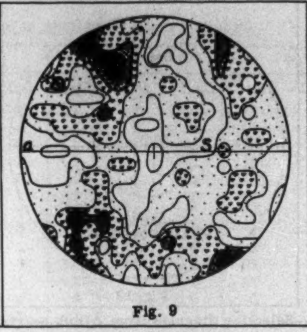

Fig. 9

Fig. 8--Diagram prepared from c-axes of quartz grains whose lamellae are plotted in Fig. 6
Fig. 9--Non-selective diagram of quartz c-axes from Ajibik quartzite (after Fairbairn [2])

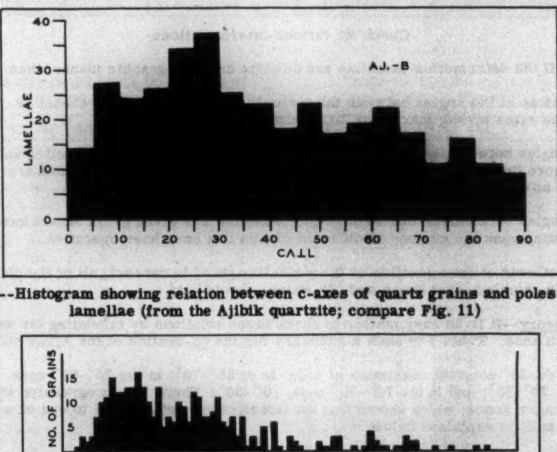

Fig. 10--Histogram showing relation between c-axes of quartz grains and poles of their lamellae (from the Ajibik quartzite; compare Fig. 11)

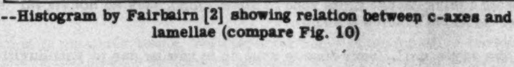

Fig. 11--Histogram by Fairbairn [2] showing relation between c-axes and poles of lamellae (compare Fig. 10)

For all grains that contained two or more sets of lamellae two additional measurements were made: (1) The angles between the planes determined by the normals to the lamellae and the c-axis; and (2) the angles between the sets of lamellae. The manner of determining (1) is illustrated in Figure 13. The poles to the planes are plotted, ⊥a and ⊥b in the example, and these points are placed on a great circle and the angle between them is read. For a grain with two sets of lamellae, one angle is read; with three, three; with four, six. To determine (2) the poles of the two sets of lamellae are placed on a great circle and the angle read.

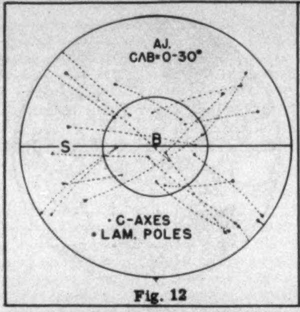

Fig. 12

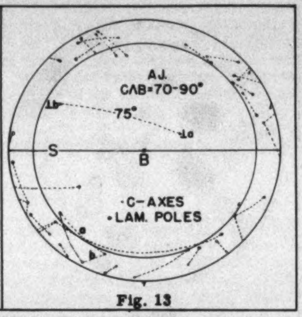

Fig. 13

Fig. 12--Selective diagram from Ajibik quartzite in which only quartz grains whose c-axes make an angle of less than 30° with B fabric axis are plotted

Fig. 13--Selective diagram from Ajibik quartzite in which only quartz grains whose c-axes make angles of 70° to 90° with B fabric axis are plotted (a and b are planes of two sets of lamellae in a single quartz grain)

Check on various interpretations

Theory--If the deformation-lamellae are definite crystallographic planes, then

(1) Tabulation of the angles between the normals to the lamellae and c-axes (c∧⊥L in the Tables) should have the same strong maximum, or maxima, in all zones.

(2) The angles between the planes determined by the normals of the lamellae and the c-axis of grains with more than one set (cL∧cL in the Tables) should be 60° if the planes are in rhombohedral zones, as has been commonly assumed.

(3) The angles between the different sets of lamellae in a given grain should have a few definite values, depending upon the number of different planes that have been operative.

If the hypothesis of the operation of the glide-line [m:r] is correct, all of the planes containing this line are in rhombohedral zones and (2), above, should hold.

Test of theory--It is an easy matter to check these relations by tabulating the various measurements for each zone. Table 1 is such a summary for the ac-section of the Ajibik quartzite.

(1) In the 0°-30° zone the maximum of c∧⊥L is at 55°-70°; in the 35°-50° zone, 45°-55°; in the 50°-70° zone, 20°-30°; and in the 70°-90° zone, 10°-30°. There is a progressive shift to lower angles in the outer zones, which shows that the lamellae are not parallel to one or a few definite planes. This shift is explained below.

(2) and (3) There is no maximum at 60° in any zone for either cL∧cL or L∧L. Such minor maxima as do appear are probably accidental, because they are not repeated in the different zones and there is no progressive change from zone to zone. Also, they do not appear in tabulations of results from other sections (Tables 2 and 3).

This shift in the angle c∧⊥L from zone to zone is in nowise due to peculiarities of orientation or measurement, because Table 2, from a section (bc) normal to the first shows almost exactly the same thing. Also, Table 3 from a different kind of rock from a different region shows essentially the same change from zone to zone and the absence of any maxima for cL∧cL and L∧L.

Explanation of previous observations

The above-mentioned tabulations show one reason why it has commonly been thought that deformation-lamellae make an angle of less than 30° with the basal plane of quartz. The lamellae do

Table 1--Measurements from ac section of Ajibik quartzite

c∧B	0°-30°			30°-50°			50°-70°			70°-90°		
° °	c∧⊥L	cL∧cL	L∧L	c∧⊥L	cL∧cL	L∧L	c∧⊥L	cL∧cL	L∧L	c∧⊥L	cL∧cL	L∧L
0- 5	0	1	0	0	6	2	1	2	0	0	2	0
6-10	0	1	2	1	1	2	3	2	2	8	2	3
11-15	0	2	1	2	0	0	5	1	2	10	1	0
16-20	0	0	0	1	0	2	6	2	2	10	0	3
21-25	0	0	0	3	0	0	9	2	2	13	1	4
26-30	1	1	0	4	2	1	8	4	1	14	0	1
31-35	1	0	0	3	1	1	5	0	2	7	3	2
36-40	1	0	0	6	0	0	7	1	0	2	2	4
41-45	1	1	0	3	0	1	4	1	0	2	2	3
46-50	2	1	1	7	1	0	4	1	2	2	2	0
51-55	1	0	1	7	0	1	2	1	2	1	1	0
56-60	6	0	0	3	0	0	4	2	0	2	2	0
61-65	5	0	2	2	0	1	1	2	3	3	1	2
66-70	5	0	0	3	0	0	0	1	3	0	4	1
71-75	3	0	0	2	0	0	1	0	2	0	2	1
76-80	3	0	0	4	0	0	2	3	1	1	0	2
81-85	4	1	0	1	0	0	1	2	1	0	1	0
86-90	0	0	1	0	1	1	1	0	2	1	1	1

Table 2--Measurements from bc-section of Ajibik quartzite

c∧B	0°-30°	30°-50°	50°-70°	70°-90°	0°-90°
° °	c∧⊥L	c∧⊥L	c∧⊥L	c∧⊥L	cL∧cL
0- 5	1	0	1	1	1
6-10	0	0	0	1	0
11-15	0	2	3	3	1
16-20	0	1	2	2	1
21-25	0	0	3	2	1
26-30	0	0	2	1	1
31-35	0	1	3	1	0
36-40	0	0	0	0	0
41-45	0	0	0	0	1
46-50	0	1	2	0	1
51-55	0	1	0	0	0
56-60	0	1	1	0	2
61-65	1	0	0	0	0
66-70	1	0	0	0	0
71-75	0	0	0	0	2
76-80	0	0	0	0	1
81-85	0	0	0	0	0
86-90	0	0	0	0	0

Table 3--Measurements from ac-section of biotite gneiss

c∧B	0°-30°	30°-50°	50°-70°	70°-90°	0°-90°
° °	c∧⊥L	c∧⊥L	c∧⊥L	c∧⊥L	cL∧cL
0- 5	0	0	1	3	0
6-10	0	0	2	3	1
11-15	0	0	3	12	1
16-20	0	0	3	6	0
21-25	0	0	2	3	0
26-30	0	0	1	1	1
31-35	0	0	0	2	0
36-40	0	1	1	2	0
41-45	0	1	0	0	0
46-50	0	0	1	0	0
51-55	1	2	0	0	1
56-60	1	4	3	1	0
61-65	0	2	0	1	0
66-70	1	1	0	0	1
71-75	1	1	0	0	1
76-80	0	0	0	0	1
81-85	0	0	2	0	0
86-90	2	1	0	0	1

have this relation in the outer zones, and there are many more lamellae in the outer zones. Thus, statistically, one is more likely to observe lamellae which form a low angle with the base.

Other things being equal, it is easier to see these lamellae than those which are more nearly parallel to the c-axis. Relative indices of refraction may have something to do with this fact; but another factor is that the quartz grains showing low angle lamellae have high birefringence, hence these lamellae are much more likely to be observed between crossed nicols than are high-angle ones.

Also, the low-angle lamellae appear to form more readily than do the others. There are fewer lamellae in rocks that are less highly deformed, but a higher proportion of those observed in such rocks have low angles. Thus, they will appear in slightly deformed rocks where there are few, or no, high-angle ones, hence they will be observed more commonly.

These factors also explain the "rule" first mentioned by MÜGGE [6] that the lamellae are always approximately normal to bands of undulatory extinction. These bands are usually parallel to the c-axis, so the low-angle lamellae do maintain this relationship, and hence it is the one usually observed. It is by no means universal, however. HIETANEN [8] sketches lamellae from Finnish quartzites which make angles of 45° with zones of undulatory extinction, and in the present work even lower angles have been observed.

Explanation of deformation-lamellae

The tabulations of measurements show that deformation-lamellae in quartz are not parallel to any definite crystallographic planes, and that they are not even confined to specific zones. Apparently, then, they are deformation-planes such as would form in homogeneous material. They do, nevertheless, appear to form more readily at low angles to the base. Theoretically there are at least three possible explanations for this relation: (1) The relations that lamellae and c-axes show to the fabric axes; (2) dimensional control; and (3) partial crystallographic control.

That they are dominantly at a high angle to the c-axis is explicable, not on the basis of the structure of quartz, but by the relation that the lamellae, and the c-axes, show to the fabric axes. (1) The lamellae are statistically parallel to $\underline{B}$. (2) The c-axes of quartz in deformed rocks have a tendency to stand at a high angle to $\underline{B}$. Given these relations, it is obvious that more lamellae will be at a high angle to the c-axis rather than nearly parallel to it. They also indicate one reason why grains in the outer zone of the selective diagrams show more lamellae, namely, merely that there are more grains in this zone.

Further, they explain the shift of the values of $c \wedge \perp L$ shown in the tables. Since the lamellae have a constant relation to $\underline{B}$ in all zones, there is bound to be a change in $c \wedge \perp L$ as the angle between c and $\underline{B}$ changes.

There are two other factors that probably have an effect on the relation of c-axes and lamellae and on the greater number of lamellae associated with grains whose c-axes fall in the outer zone. These factors have not been studied quantitatively with respect to the above-mentioned relations, but attention is called to them in order that other observers may keep them in mind and perhaps check on their effects:

(1) Quartz grains in deformed rocks tend to be elongate parallel to their c-axes or to the unit rhombohedron. INGERSON and RAMISCH [9] found such elongations in a number of rocks of the District of Columbia Area, and in the few rocks studied from other areas. Figure 14 illustrates this tendency in one of the rocks from the District of Columbia Area.

(2) Lamellae tend to form at a high angle to the long dimension of a grain, regardless of the position of the c-axis. This is particularly true of slightly deformed rocks, but lamellae also form in equant grains in more highly deformed rocks, or in those all of whose grains are more or less equant.

If these factors are general, they contribute to the explanation of the relations of lamellae, fabric-axes and crystallographic axes of quartz, described above. They are almost certainly operative in some cases.

Thus, the lamellae are *indirectly* related to the structure of quartz because both are related to the fabric-directions. It is probable that development of preferred orientation of the c-axes and production of lamellae were simultaneous.

Directional relation of poles of lamellae and c-axes

When poles to lamellae and c-axes for the same grains are plotted and related by lines, it is apparent that the lamellae-poles are almost invariably on the same side of the c-axis. Figure 15 shows this relation clearly. It is from the $\underline{ac}$-section of a drag-folded mica schist from the lower part of Soapstone Run, D. C., about 200 yards above its junction with Rock Creek. Some of the measurements have been omitted for the sake of clarity. The lamellae-poles are between the c-axes of quartz grains and the $\underline{a}$ fabric axes.

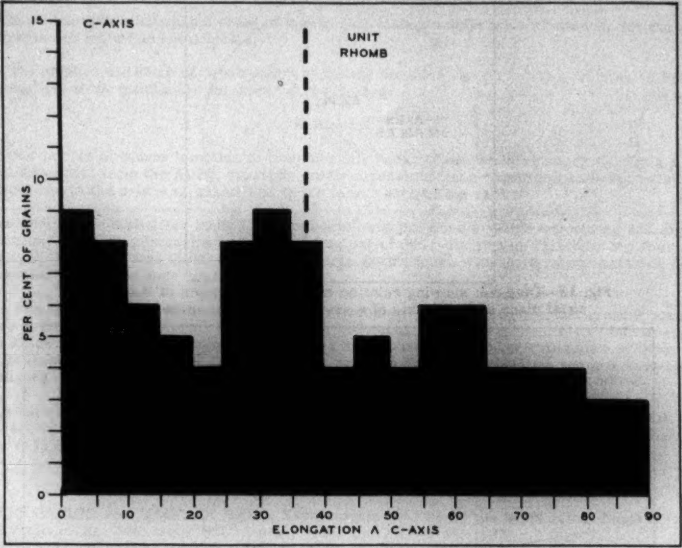

Fig. 14--Histogram showing relation of elongation and crystallographic directions in unbroken quartz grains from a weathered metamorphic rock

A possible explanation for this fact is given in Figure 16. The arrows indicate the direction of compression. The quartz crystal shown has its c-axis in the position of a maximum in the quartz diagram of such a rock. The solid and dashed lines across the crystal represent probable positions of shear-planes along which the crystal might be expected to fail. If the force is resolved into components parallel and normal to each of these planes, the one represented by solid lines has the larger component parallel to it, whereas the dashed one has the larger component normal to it. Failure will therefore take place along the planes represented by the solid lines. The pole to this plane lies between the c-axis of the quartz grain and the a fabric axis.

Development of c-axis maxima

If the lamellae really represent planes along which quartz has been plastically deformed, and if they tend to form approximately normal to the c-axis, whatever the reason, then they may provide at least part of the explanation of how preferred orientation of the c-axes of quartz is developed in deformed rocks. If the individual quartz grains rotate during a deforming movement, then, when a given grain approximates the position indicated in Figure 16, lamellae will begin to form. Thereafter the motion will be taken up by motion along the lamellae rather than by further rotation of the grain and the position of its c-axis remains constant. As other c-axes come into this position, they also become "fixed" and there is an accumulation of axes in the ac-plane, approximately halfway between a and c (SANDER'S maximum III). Figure 16 shows this position schematically, and Figure 3 illustrates a statistical determination of it in a rock.

Use of lamellae in interpretation

(1) A statistical study of orientation of lamellae can reveal the positions of the fabric axes when they cannot otherwise be located either macroscopically or microscopically, as in a massive quartzite without mica in which the c-axes are not highly enough oriented to give an accurate result.

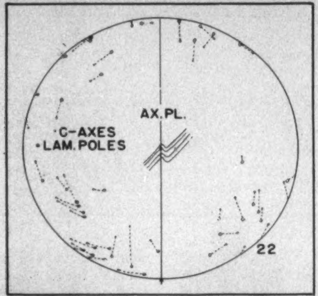

Fig. 15--Diagram showing relation of c-axes and poles of lamellae to axial plane and fold-axis of a small drag-fold in mica schist

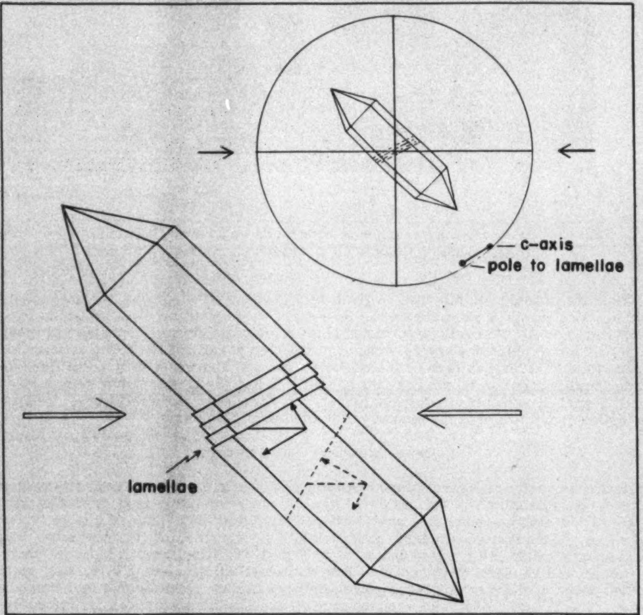

Fig. 16--Schematic diagram to illustrate a possible explanation for observed relations shown in Fig. 15

(a) The B-axis is parallel to the lamellae; that is, normal to the girdle of lamellae-poles.

(b) If poles to lamellae and c-axes are plotted for the same grains, the poles "point" to the a-axis; thus all three fabric-axes can be determined even when there is no visible s-plane.

(2) In a rock with mica such a study of quartz lamellae can determine whether or not the axes of the quartz and mica fabrics coincide.

(3) The number and state of development of quartz lamellae can be used as an index to intensity of deformation, if the quartz has not been recrystallized.

Summary

Measurements of quartz lamellae in metamorphic rocks of the Washington, D. C., Area and new measurements from the Ajibik quartzite confirm previous generalizations as to the relations of the lamellae to the c-axis of quartz and to the fabric axes of the rocks.

A more detailed statistical study than has been made previously yields interesting and significant results. This study is carried out by dividing each fabric-diagram of lamellae into four zones according to the angles that the c-axes of the quartz grains make with the B fabric-axis and tabulating measurements for each zone.

The tabulations show that the lamellae are not controlled by definite crystallographic planes or zones in the quartz structure. They are apparently controlled almost entirely by the stress pattern which determined the (quartz) fabric-axes for the rock. Since the orientation of the c-axes is also at least in part controlled by this pattern, there is an indirect relation between lamellae and the structure of the quartz.

Lamellae can be important in geologic interpretation in determining not only the B-axis, but also direction of motion, if the lamellae and c-axes of the same grains are plotted. Lamellae can also serve in certain cases as an index of intensity of deformation.

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(See also pp. 48, 94, 134, and 137)

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LOW-ANGLE NORMAL FAULTS IN THE BASIN-AND-RANGE PROVINCE

Chester R. Longwell

Introduction

Published data imply that normal faults in general are steeply inclined, and it is commonly assumed that faults of this class have developed habitually with dips of 45° or more. The writer has not seen in the literature many descriptions of large normal faults that have conspicuously low dips. Those that dip 25° or less usually are assumed to have been rotated from initially steep inclinations. Moreover, few published descriptions of large normal faults known to the writer cite evidence of decreasing dip with increasing depth, to indicate concavity of fault-surfaces toward the hanging wall. Indeed, some structural geologists have argued that evidence favors steepening of ordinary normal faults downward, with resulting concavity toward the footwall-block [see 12 of "References" at end of paper]. Pronounced concavity of a fault-surface toward the hanging wall has been interpreted as a characteristic of superficial "landslide-faulting" [13].

Some years ago the writer studied the structure of several ranges in the Las Vegas Quadrangle of southern Nevada (Fig. 1). One of these, the Desert Range, is a steeply tilted block cut by low-angle normal faults of large displacement [7]. Similar faults dip into the flank of the Virgin Mountains, in the Grand Wash District, about 75 miles southeast of the Desert Range [8]. The Grand Wash and Desert Range groups of faults are alike in their relation to large-scale anticlinal structure; the faults in each group dip into the limb of a major anticline, several miles distant from the anticlinal crest. Furthermore, some of the fault-surfaces in each area are conspicuously concave

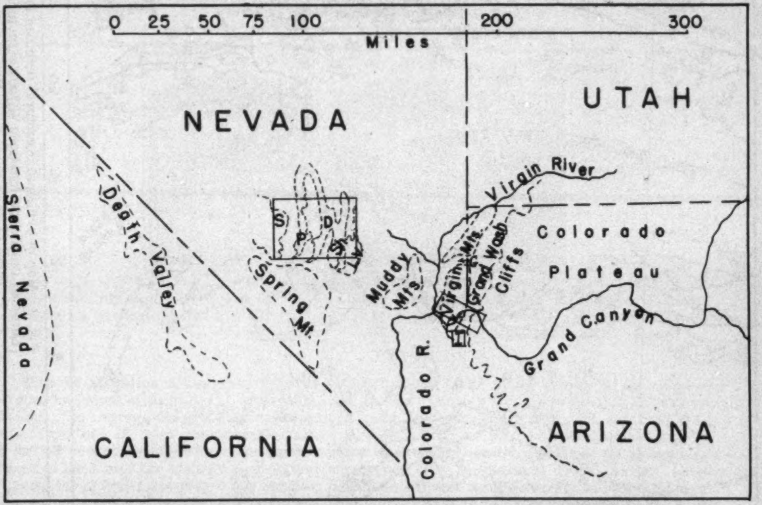

Fig. 1--Index map showing locations of the two groups of faults discussed in text [Larger rectangle is area of Fig. 2; S = Spotted Range; P = Pintwater Range; D = Desert Range; Sh = Sheep Range. Faults of Grand Wash (shown in Fig. 12) are in area of smaller rectangle; I = Iceberg Canyon; G = St. Thomas Gap]

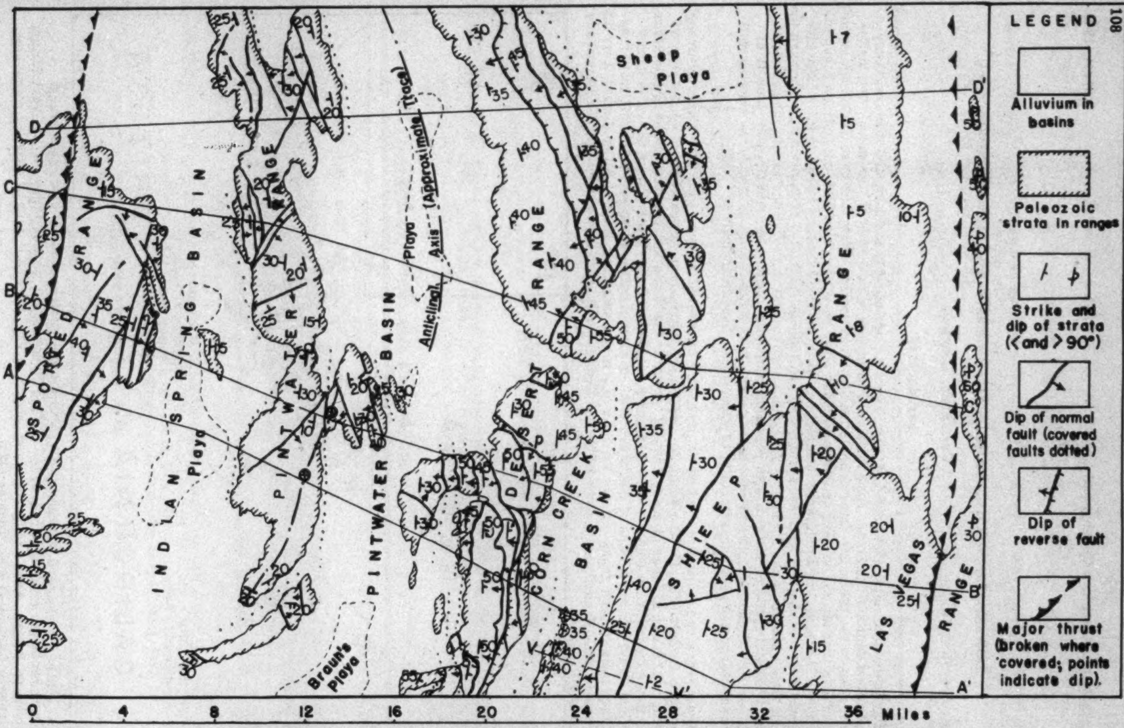
LEGEND
Alluvium in basins
Paleozoic strata in ranges
Strike and dip of strata (< and > 90°)
Dip of normal fault (covered faults dotted)
Dip of reverse fault
Major thrust (broken where covered; points indicate dip).
SPOTTED RANGE
INDIAN SPRING BASIN
Playa
PINTWATER RANGE
PINTWATER BASIN
Anticlinal Axis (Approximate Trace)
Playa
Braun's Playa
DESERT RANGE
CORN CREEK BASIN
Sheep Playa
SHEEP RANGE
LAS VEGAS RANGE
A
A'
B
B'
C
C'
D
D'
V
V'
0
4
8
12
16
20
24
28
32
36
Miles

Fig. 2--Map of principal structural features in northern half of Las Vegas Quadrangle, Nevada [Lettered lines show locations of four structure-sections (not reproduced here); V - V' = mid-line of airview shown in Fig. 9; ranges shaded, alluviated basins white] toward the crest of the associated anticline.

Faults in the Desert Range

The Desert Range, in the northern part of the Las Vegas Quadrangle, is a tilted block of Paleozoic strata which not long ago geologically was almost, if not entirely, buried under basin-sediments. Its present relief and excellent exposures of bedrock are due to exhumation, which resulted in part from exterior drainage in Pleistocene time, and in part from recent downfaulting of the basin occupied by Sheep Playa (Fig. 2). The highest points on the range are about 3,000 feet above adjacent basin-floors. Bedrock consists of sandstone, shale, limestone, and dolomite, ranging in age from Cambrian to Devonian, with total thickness about 20,000 feet. Throughout the range the strata dip eastward, at angles ranging from 30° to 75° and averaging about 50°. This apparently simple homoclinal structure is complicated by westward-dipping faults that have caused numerous repetitions of formations (Figs. 3, 4).

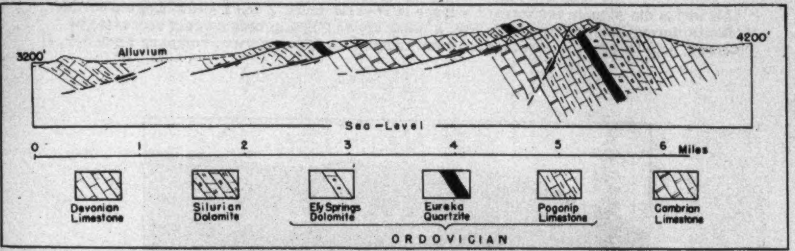

Fig. 3--Typical cross-section, west-east, through the southern part of the Desert Range (vertical scale same as horizontal)

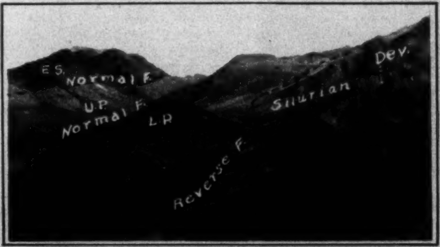

Fig. 4--View north near summit of Desert Range
[All strata dip eastward, 50° to 60°; L.P. = lower Pogonip limestone; U.P. = upper Pogonip limestone (Ordovician); E.S. = Ely Springs dolomite (highest Ordovician); compare Figs. 2 and 3]

With the exception of one steep reverse fault, all of the faults in any section of the range are normal, and most of them dip at remarkably low angles. Those with dips exceeding 25° are uncommon; the average dip probably is between 15° and 20°, and some of the fault-surfaces are inclined less than 10° over considerable areas. Each of the larger faults can be traced along the strike for several miles, until it disappears under sedimentary cover. Because of the low dips, traces of the faults are sinuous in irregular topography (Fig. 5). Several of the "slices" between adjacent large faults are only a few hundred feet thick. On the west slope of the range these "slices" are much dissected, and some are represented only by isolated remnants on the higher divides (Figs. 6, 7). Only those faults with large displacement are shown in the sketch map (Fig. 2); there are many "sympathetic" faults of limited extent and small displacement. Representation of the faults is less complete for the northern than for the southern part of the range; some low-angle faults that displace Lower Cambrian strata on the western slope of the range in the northern part of the area have not been mapped.

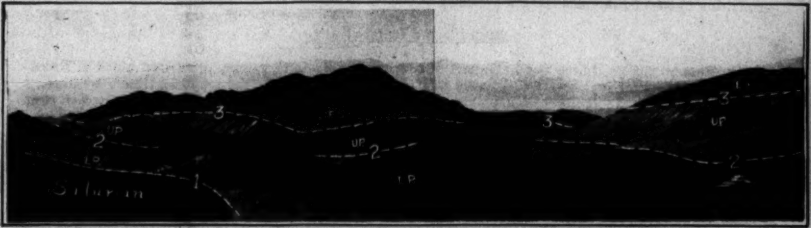

Fig. 5--View westward near top of Desert Range
[All strata dip steeply eastward; 1 = trace of reverse fault; 2 and 3 = low-dipping normal faults; formations lettered as in Fig. 4; weak upper Pogonip beds largely concealed by debris; note that fault 3 retreats far down cross-valley, out of view; compare Figs. 2, 3, 4]

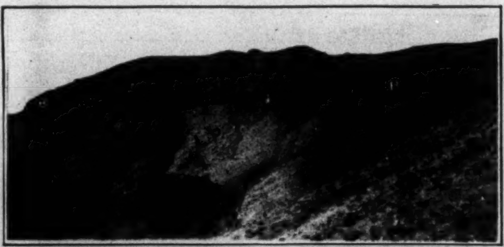

Fig. 6--Remnant, on divide, of hanging-wall block made of upper Pogonip limestone (U.P.)
[Trace of normal fault shown by broken ink-line; lower Pogonip (L.P.) limestone in footwall; dip-displacement, about 800 feet, indicated by dislocation of the bed B; bedding in upper block, obscured by rubble, shown by broken ink-lines]

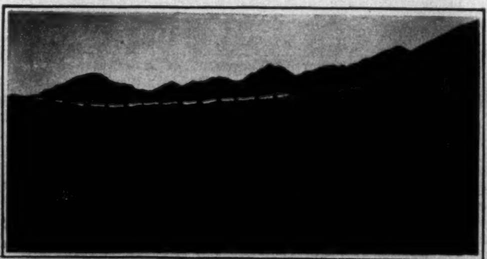

Fig. 7--Remnant, on divide, of hanging-wall block made of Silurian dolomite, which is in place, in footwall, on ridge beyond view at right
[Dip-displacement, 3500 feet; beneath fault (broken white line) is Pogonip limestone, succeeded (at right) by Eureka quartzite (white) and Ely Springs dolomite (black); note that fault must be distinctly concave upward to clear the slope, and at left its dip is slightly reversed]

Dip-displacements on the larger low-angle faults vary from hundreds to thousands of feet. The largest measurable displacement is on the Prospector Fault, which is marked P in Figure 2. The trace of this fault, clearly visible in many excellent exposures that are supplemented by stratigraphic and topographic evidence, has an oblique course entirely across the range. This fault is of such interest that it is represented to larger scale, with its geologic setting shown in some detail (Fig. 8). The fault-surface dips southwestward fairly uniformly at about 17°. North of the fault-trace is a thick section of Lower Cambrian strata, dipping steeply eastward; south of it, strata with similar structure range in age from Middle Cambrian to late Ordovician. It is an obvious deduction that the fault is one of the group of normal faults with low westward dips, and that north of the fault-trace the hanging-wall block has been removed by erosion. This conclusion is strengthened by the presence, nearly three miles to the north, of a similar fault-surface dipping gently northward beneath a hanging-wall block of Ordovician and Cambrian limestones. Clearly, there has been strongly localized upwarping athwart the range along an axis trending about north 60° west. Several steep faults that have this trend in a zone directly north of the Prospector Fault had a part in the uplift, in sympathy with the upwarping.

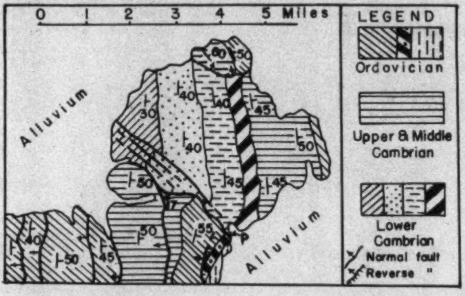

Fig. 8--Geologic map of area adjacent to the Prospector Fault, P (see Fig. 2)

Along the Prospector Fault the youngest Ordovician beds present in the district lie in the hanging wall in contact with the highest formation of Lower Cambrian age in the footwall-block. The intervening stratigraphic section measures about 7,500 feet. If we assume that before upwarping occurred the fault dipped westward 15°, and if the average eastward dip of strata in the hanging wall is taken as 50°, the dip-displacement on the Prospector Fault near its outcrop is about 8,300 feet. There is comparable displacement on the largest of the faults represented in Figure 3. Cumulative dip-displacement on the several low-angle faults exposed in the southern part of the range amounts to more than four miles.

Several features of the faults merit more detailed field-study than they have received thus far. One of these is the upward-concavity of all fault-surfaces that are exposed extensively enough for accurate appraisal of their form. Remnants of blocks on ridges between canyons furnish the best opportunity for quantitative measurements (Figs. 6, 7). Enough data are in hand to permit some estimates of radius of curvature, on the assumption that cross-sections of the faults are circular arcs. Accurate mapping of the entire range with this particular problem in mind should provide the basis for more confident results. Fault-surfaces that obviously have been deformed by warping—for example, the Prospector Fault surface--are,of course,excluded from consideration. Radii of selected arcs studied thus far range from 15,000 feet to more than 20,000 feet. No systematic relation between radius of curvature and other items, such as amounts of displacement or positions of faults in the belt, is apparent from the limited data now available.

In the search for a logical mechanical explanation of the faults, an obvious question is their possible relation to other major structural features of the region. In spite of the excellent exposures in individual ranges, of course much of the overall structural pattern is concealed by debris-cover in the wide intermont basins. It has been determined, however, that the area lies in a belt of major thrust-faults which strike generally north-south [4]. Two of these thrusts, nearly 40 miles apart, are shown in Figure 2. Two thrusts of lesser magnitude have been obscured by later normal faulting and erosion; one near the western margin of the Sheep Range, the other on the west side of the Pintwater Range. A major anticline, whose axial trace is essentially parallel to the traces of the thrusts, has the Pintwater and Desert ranges in its opposed limbs (Fig. 2). The reality of this major fold might be questioned if no better basis for it were known than the relationship between faulted and discontinuous bedrock-units shown in the map. Fifteen miles north of the map area, however, these two ranges converge and finally unite in the plunging nose of the great fold; this simple relationship is suggested in the index map (Fig. 1). A nearly continuous section reaching several miles eastward from the crest of the anticline is afforded by the long spurs projecting into Pintwater Basin from the Pintwater and Desert ranges (Fig. 2). As shown on the map, the axial trace appears strongly displaced from the southern part of the Pintwater Range to the middle of Pintwater Basin. It is not clear whether this represents actual dislocation on hidden faults or échelon arrangement within a compound anticline.

The much-faulted east limb of the anticline extends through the Sheep Range, some 20 miles from the axial trace (Figs. 2, 9). The west limb, broken by a large graben in Indian Springs Basin,

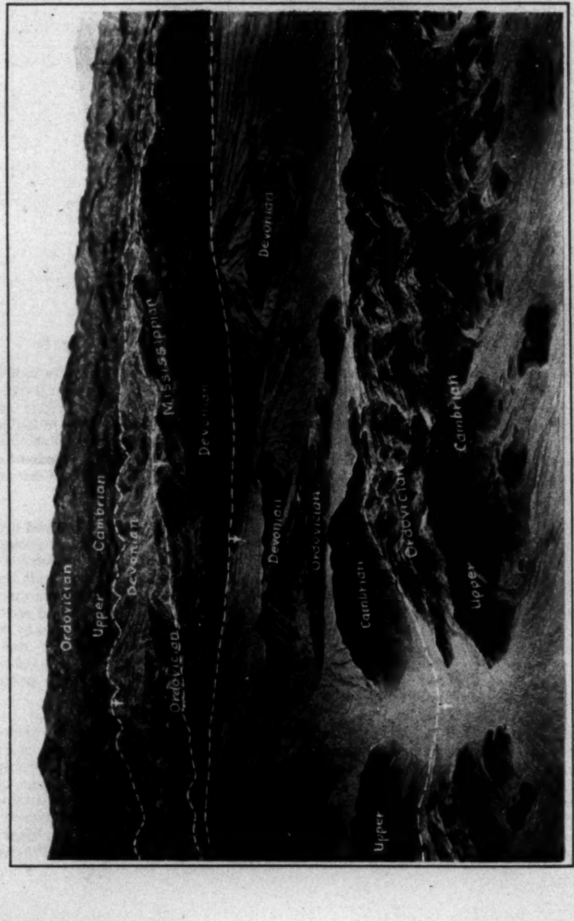

Fig. 9--Airview eastward to summit of Sheep Range, about five miles distant from foreground; middle of view is along line V - V' of Fig. 2
[Note repetition of formations by four large normal faults (white broken lines); all strata dip away from observer, 40° in foreground, 20° near top of range; Silurian strata are present, but not labelled on photograph]
(Copyright by Spence Air Photos)

extends into the Spotted Range to the outcrop of a large thrust, about 15 miles from the axial trace. This thrust, in connection with another two miles farther west, complicates the structure, and seems to be responsible for the apparent discrepancy in dimensions of the two limbs. Reconstruction of the anticline as a simple arch, by reasonable upward projection of strata in the Sheep Range and replacement of fault-blocks farther west, would lift any horizon on the axial trace in the southern part of the Pintwater Range to a height more than 30,000 feet above its present position. The formation now at the surface in this axial position is the Pogonip limestone of the Ordovician system. Younger formations, up to and including Jurassic strata, that once were continuous over the area have an average total thickness of about 18,000 feet. If any considerable part of this sedimentary cover were restored over the reconstructed simple arch, the crest would have fantastic altitude. It seems probable, as explained in later paragraphs, that many of the large faults developed concurrently with growth of the anticline, and that progressive collapse by faulting prevented excessive height of the structure at any stage. Probably, also, a large total thickness of the sedimentary section was removed, slowly but continuously, as the crest of the fold was pushed upward into the mill of erosion. Block-faulting of much later date may have lowered the arch still further, but such an effect is not determinable quantitatively.

Inspection of the map (Fig. 2) reveals a remarkably systematic arrangement of the faults in relation to the major anticline. On the east limb, throughout the 20-mile-wide belt extending into the Sheep Range, the faults almost without exception dip westward, toward the axial plane of the fold (Fig. 9). On the west limb--in the Pintwater and Spotted ranges--fully two-thirds of the important faults dip eastward, toward the axial plane of the fold; most of the exceptions probably are related to subsidence along the east side of Indian Springs Basin, at a comparatively late date. Normal faults with conspicuously low dips have been observed only in the east limb of the fold, and lie in a belt five to ten miles distant from the axial trace. Similar faults in the west limb may be concealed under the floor of Indian Springs Basin. Careful field-search may yet reveal faults of this type in marginal parts of the Spotted and Pintwater ranges.

Possible genesis of the low-angle faults can be considered more profitably in the light of additional information from another area.

Faults in the Grand Wash District

West of the Grand Canyon, in western Arizona and southern Nevada (Fig. 1), many structural features of unusual interest have been laid bare through action of the Colorado River [8]. In particular, the stream has cut canyons through several fault-blocks made of the bedrock-formations that are well exposed and almost undisturbed in the Grand Wash Cliffs, at the edge of the Colorado Plateau. The fault-blocks are inclined steeply eastward, and some of them are still partly buried in basin-debris that accumulated after the faulting occurred. About ten miles west of the Cliffs the river for several miles had its course parallel to the strike, between two of the blocks, and there Iceberg Canyon was cut to a critical depth, exposing one of the faults ideally for field-study (Fig. 10).[Unhappily the waters of Lake Mead now conceal the fault, except for a short stretch directly north of Iceberg Canyon.] West of the canyon the fault disappears with an average westward dip of about 10°. Up the dip, toward the east, the inclination is progressively steeper to a maximum of 30° at the highest point of exposure. In cross-section the fault-surface describes a nearly perfect circular arc, with radius of curvature about 15,000 feet (Fig. 11).

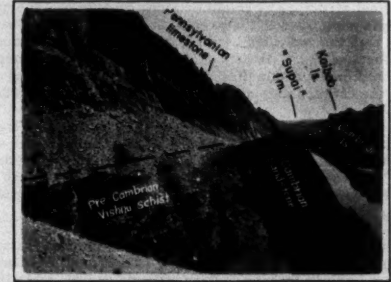

Fig. 10--View northward up Iceberg Canyon to bend in Colorado River two miles distant [Attitude of fault in foreground indicated by broken black line; steeper dip at higher level shown by white dots]

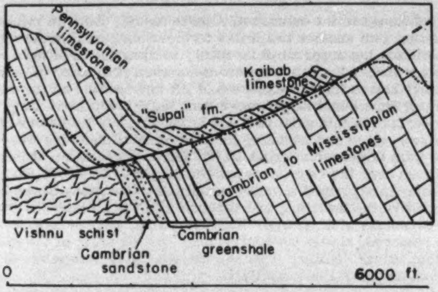

Fig. 11--Average cross-section of the Iceberg Canyon Fault, based on exposures in the two-mile stretch shown in Fig. 10

[Dotted line represents cross-profile of valley in foreground of view, corrected for perspective to integrate with section in background]

At least one other important fault west of Iceberg Canyon is similar in form and attitude to the fault described above. Evidence farther north suggests that two additional faults in the group may be located still farther west; but it would be difficult to recognize them in the gneiss and granite that underlie the surface in a wide area (Fig. 12). The fault two miles east of Iceberg Canyon also has a surface concave toward the west; however, it is not well exposed, and the part above the river dips 40° to 50°. The Grand Wash Fault, which appears to be the largest of the group, is buried between Tassai Ridge and the plateau. Possibly the basin-debris in this belt conceals more than one important fault; however, a single large block inclined eastward from Tassai Ridge, as suggested in Figure 12, represents the simplest structure possible based on the available evidence. If one fault is responsible for lowering this block from the plateau-level, throw of the fault must be of the order of 20,000 feet. Even if two or more concealed faults share the displacement, it is highly probable that each fault-surface is concave toward the west. This conclusion is based not only on forms of the faults exposed in and near Iceberg Canyon, but also on consideration of the mechanical requirements for rotation of the visible blocks to their present attitudes.

The faults of the Grand Wash Group dip into the east limb of a major anticline, as indicated in Figure 12. In an earlier stage of study the writer failed to recognize this important relation [9, pp. 434-436]. Since pre-Cambrian rocks at fairly high altitudes extend to the western side of the range, and since a large normal fault separates these rocks from younger formations in Virgin Valley, the southern part of the range was interpreted as a great eastward-tilted fault-block, complicated by the Grand Wash zone of faults. It is now clear that the entire Virgin Mountains belt is a complex anticlinal uplift, greatly modified by faulting. In the northern part of the belt the general anticlinal structure is easily recognized [5]. Structural as well as topographic continuity is interrupted by St. Thomas Gap (Fig. 1), which marks a zone of profound downfaulting, south of which the anticlinal structure is resumed along an axis en échelon to that farther north. This southern axis plunges northward in the area of St. Thomas Gap. Nearer Colorado River the anticline is structurally high, as indicated by the belt of pre-Cambrian rocks, more than 15 miles wide, exposed at the present surface. In that part of the range no sedimentary formations mark the western limb of the fold; presumably they have been faulted down and covered with later deposits in Virgin Valley, the eastern side of which is marked by an important zone of faulting.

The height to which the anticline initially reached in the southern Virgin Mountains can not be determined from evidence that has survived erosion. The reconstructed section (Fig. 12) suggests that the core of pre-Cambrian rocks extended to a height considerably above the top of the sedimentary section in the Colorado Plateau east of the fold. If there are any faults west of the axis comparable to those in the eastern limb, evidence of them has been removed by erosion or has escaped notice in the complex pre-Cambrian bedrock.

Thus the known faults in this group are more restricted in numbers and in distribution than are those in the Desert Range and vicinity. However, exceptional exposure of the Grand Wash faults, and especially of the one in Iceberg Canyon, throws considerable light on certain features which in themselves may seem puzzling. A fault whose cross-section curves through 90° of

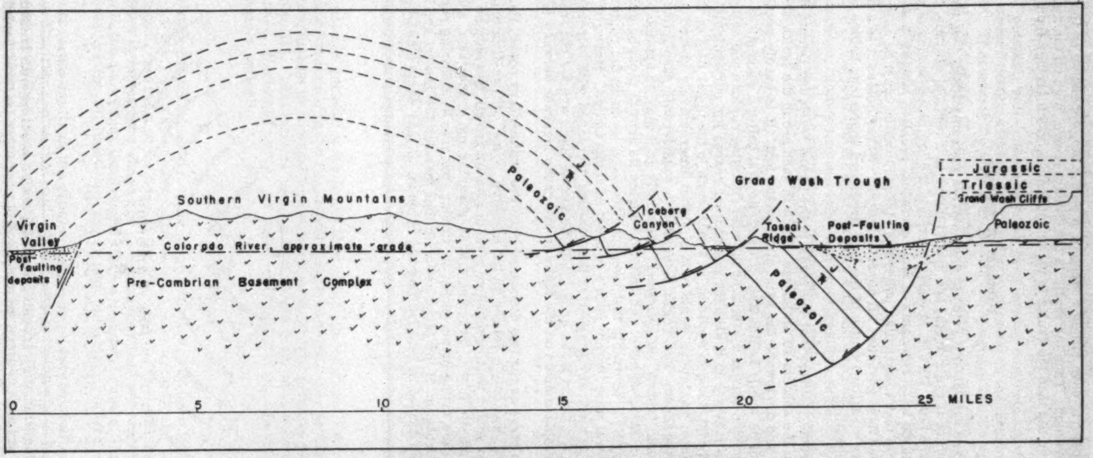
Southern Virgin Mountains
Virgin Valley
Post-faulting deposits
Colorado River, approximate grade
Pre-Cambrian Basement Complex
Paleozoic
TR
J
Iceberg Canyon
Grand Wash Trough
Tassai Ridge
Post-Faulting Deposits
Jurassic
Triassic
Grand Wash Cliffs
Paleozoic
Paleozoic
TR
J
0
5
10
15
20
25 MILES

Fig. 12--Cross-section from Virgin Valley to Colorado Plateau, with diagrammatic reconstruction of the Virgin Mountains anticline

[Triassic and Jurassic formations, with thicknesses shown in broken line, are present farther north on Plateau and adjacent to Virgin Mountains, but have been eroded in area of section; features of section explained in text] circular arc may appear to have either a steep or a gentle dip, depending on the level at which the fault is exposed by erosion. Thus the faults in the Desert Range, high on the anticlinal limb, logically have much lower dip than the faults in the Sheep Range, much farther from the crest of the fold.

Problem of genesis

More than 60 years ago McGEE tried to demonstrate mathematically that normal faults should be essentially horizontal at great depth, and should curve to a vertical attitude, or even past the vertical, at the surface [10]. DAVIS, seeking to explain the low slope-angles of some triangular facets, which he believed to be remnants of fault-surfaces, recalled McGEE'S solution [2]. It is, of course, not conceivable that a particular pattern of stresses, which must be assumed for a mathematical treatment, can have governed all normal faulting. Nevertheless, it is a matter of some interest that theorists visualized faults of the type described above long before they were demonstrated by field-observation.

The inference seems justified that the faults in the Grand Wash and Desert Range groups are genetically related to the associated anticlines, since in each group the faults strike closely parallel to the axial trace and dip toward the axial plane of the fold. It is hardly credible that a relationship so consistent can be wholly accidental. This structural pattern suggests at once the time-honored concept of tension across a rising arch, with resulting rupture and collapse. Those who favor this explanation may see in it also the mechanical reason for curved fault-surfaces; according to the general concept, tension would be at a maximum in the upper part of the fold, in the region of the axial plane, and blocks would tend to slump progressively inward from both limbs, after the fashion of landslides. The writer confesses to considerable skepticism toward this common notion of "tensional failure" in anticlines, especially as it may be applied to faults of such large scale as those considered here. An anticline during its growth must be under great confining pressure, and it is hardly conceivable that tensional stresses adequate for rupture could be in control to a depth of several miles within such a product of compression. Moreover, in neither major fold considered here is there any suggestion that faulting decreased with increasing distance from the crest; indeed, in the Grand Wash area all of the known faults are far out from the axial region of the anticline, and displacements on the faults in the group increase outward (Fig. 12).

In an anticline as large as the two discussed here, the sedimentary cover, though it was from two to five miles thick, was only a veneer on the massive "core" of pre-Cambrian rocks. Movements and stresses in such a welt of massive rock during its growth can only be conjectured. Presumably there was "plastic flow", including minute shearing and granulation, and the sedimentary cover was adjusted to the rising mass, partly by flexing, but also by shearing rupture. Figure 13 is a schematic representation of the large anticline that includes the Desert and Pintwater ranges, omitting complications caused by late faulting and erosion. It may seem plausible to reconstruct

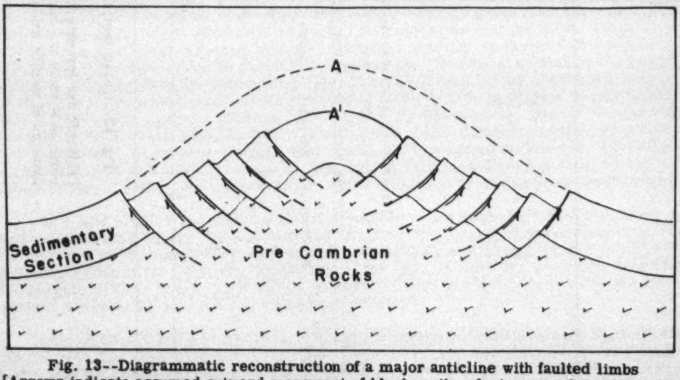

Fig. 13--Diagrammatic reconstruction of a major anticline with faulted limbs [Arrows indicate assumed outward movement of blocks; other features explained in text; dips of faults exaggarated] the anticline and compute its initial height by sliding the fault-blocks out to the broken line through A. However, it becomes clear that in this operation large gaps will open between some of the blocks, not to mention the large empty space that will appear beneath them. Advocates of "tensional failure" will point to the gaps as the measure of extension by upbending, and will designate the empty space as the "potential void" into which the fault-blocks continuously collapsed. Another analysis appears to accord better with the high confining pressures that must have obtained within the growing anticline. Throughout the period of growth the weight of the rising mass would partly counterbalance upward pressure, creating a tendency to spread the anticline laterally. Shearing stresses would cause rupture of the cover, with differential outward movement of fault blocks as indicated by the arrows in Figure 13. These faults would extend outward from the region of "plastic flow", through an "outer shell" consisting of the sedimentary cover and a considerable thickness of massive pre-Cambrian rocks beneath. Extension of this passive shell in the way suggested here would not in any sense reflect tensional stresses as the cause of the faulting.

Upward curvature of the fault-surfaces presents a difficult problem for theoretical treatment, because numerous unknown factors are involved, and questionable assumptions are required for any conclusion. Experiments in the laboratory, prepared to proper scale and guided by all field-data now in hand, may throw light on this aspect of the general problem.

Extension of surface in areas of large-scale normal faulting is a perennial subject of discussion. Many geologists have assumed without serious question that extension is required for accommodation of the moving blocks. However, as NOLAN, following RUBEY, correctly states [11, p. 182], in adjustment of tilted blocks separated by curved faults "the shortening due to tilting may be of greater magnitude than the extension resulting from normal faulting". Moreover, regional shortening due to large-scale folding may equal or exceed local extension through movement on superposed normal faults. The point is well illustrated by Figure 12, which was not planned as such an illustration. In the Grand Wash Trough, as measured along the top of the Paleozoic section, movement of the three fault-blocks has caused an extension of 1.2 miles, or about 30 per cent of the original distance. However, measurement across the entire section, including the anticline as reconstructed, shows no change in length; shortening by compression has exactly balanced the extension by faulting. This, of course, proves nothing for the province as a whole. However, it serves to emphasize the warning that easy assumptions of "regional extension" ignore some fundamental elements in the problem.

There is no intention to suggest that all normal faults in the Basin-and-Range Province are of the type described here, or that tilted fault-blocks everywhere are associated with large-scale anticlinal structure. It will not be surprising, however, to find that many of the faults associated with such blocks, and now represented in published structure-sections as plane surfaces, are actually curved in cross-section. BAILEY reports that one of the important faults near Logan, Utah, has a dip of 30° or less near the base of the range [1]. Unfortunately, opportunities to observe any such fault through a considerable vertical range, as in Iceberg Canyon, are not common. Mines located in critical localities may yield more information bearing on this problem than is now available.

Comments on possible genesis of the faults should not close without reference to GILBERT'S suggestion that visible structure in the Basin-and-Range Province may be the result of adjustments to deeper-seated deformation in contrast to the more superficial "primary phenomena" exemplified by Appalachian folding [3]. This general concept is strongly favored by the relation between faults and anticlinal structure, discussed above. As noted by GILBERT, the adjustments probably do not follow a uniform, simple pattern.

Date of faulting

No definite evidence for dating either of the large anticlines has been found. Thick sedimentary deposits derived from the Virgin Mountains uplift accumulated in the Grand Wash Trough after the latest movement on the great fault at the edge of the Plateau [8]. These deposits have yielded no fossils, and in relation to formations whose age is established they are merely "post-Jurassic". Between the ranges in the Las Vegas Quadrangle there are fanglomerates, lacustrine siltstones and limestones, and volcanic tuffs, all likewise younger than Jurassic but otherwise undated.

Some of the great thrust-faults of the general region were developed after deposition of early Upper Cretaceous sediments, and on this basis the thrusts are referred to the "Laramide" orogeny. Since both of the large anticlines trend generally parallel to the thrusts, the presumption is that they reflect the same episode of regional compression. On this basis the normal faults in the two groups described here probably developed not later than early Cenozoic time. This conclusion may seem inconsistent with evidence of movements so recent as to be recorded in broken fan-slopes bordering the Sheep Range [6]. However, as NOLAN emphasizes [11], there is evidence of recurrent movements on many of the basin-range faults at widely spaced dates.

It is a common concept that the Basin-and-Range Province was deformed by one or more episodes of compression, with development of thrusts and folds, and that the normal faults record a much later and radically different structural history, marked by "crustal relaxation and tension." Indications that many of the great normal faults in the region were initiated at an early date, in connection with major compressive deformation, call for reconsideration of sweeping conclusions on this subject that are now in print and widely accepted.

Acknowledgments

Although an attempt is made to recognize in formal references the chief sources of information and ideas contributed by others to development of this topic, doubtless the acknowledgments for this aid are incomplete. Field-studies that have provided the chief basis for the paper were supported, over a period of several years, by the Geological Society of America, the United States Geological Survey, and Yale University.

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PROGRESS-REPORTS

PROGRESS-REPORT ON THE NATIONAL GEOGRAPHIC SOCIETY-CORNELL UNIVERSITY STUDY OF AURORA

C. W. Gartlein

The National Geographic Society has made it possible to continue the study of aurora at Cornell and we have been able to speed up some of our work.

The recording of all auroral occurrences was of sufficient importance that the observer-group has been enlarged so now there are 25 stations ranging from Oregon to Prince Edward Island and north of Lake Superior to Ithaca. Five stations of the United States Weather Bureau and several in Canada give reports based on hourly observation each night.

For correlation-purposes the aurora is hard to classify, especially on those nights when only one station has had clear weather. Since we do not know what aspect is most important, it seems advisable to use several aspects. The work reported last year seems to indicate that the maximum of any aspect in a given three-hour period gives a reasonable correlation with the K-figure. As shown in Table 1, we have chosen brightness, geomagnetic latitude of southern border, form of aurora, number of forms, east-west motion, and duration as reportable quantities. The code and meaning is shown in each case. Little comment is needed except on the following items: The form is reported as the highest which has occurred. In many cases the two form figures enable one to say closely which of the 12 have been seen. Thus a report "4" for form and "5" for number of forms means that five of six possible ones have been seen. A report of "5" for motion indicates that movement of the forms has been in one direction and then in the other.

Table 1--Code for reporting auroral observations for three-hour periods
(The highest value attained for each aspect is reported)

Code	Brightness	Range, lat., north	Form	No. of forms	Motion	Duration
0	None	N. of 66	Cloudy	10±	None	Not certain
1	VF	64-66	G	1	Slow E→W	First hour[a]
2	F	62-64	HA HB	2	Fast E→W	Second hour[a]
3	F-M	60-62	DS	3	. . . .	Third hour[a]
4	M	58-60	RA RB	4	. . . .	Any two[a]
5	M-B	56-58	R	5	Both	Only in first hour
6	B	54-56	C D	6	Slow W→E	Only in second hour
7	B-VB	53-54	PA PS F	7	Fast W→E	Only in third hour
8	VB	52-53	Non-ray + puls.	8	. . . .	Two hours
9	VB+	S. of 52	Ray + puls.	9	Rippling	All three hours

[a] Observation only for part of period.

If we assume the height of the aurora to be normal then it is easy to draw up a table of geographical position for each elevation for each reporting station. Thus overhead in Timmins, Ontario, is "4", while overhead in Ithaca is "7". Thus finding the geomagnetic latitude becomes a matter of looking up the value opposite the entry for elevation for the station. The code is not perfect but it seems better than any given before.

A perusal of many records indicates that stations of the same geomagnetic latitude see much the same thing, while more northerly stations see a larger display. There is usually little evidence for diurnal influence and in many cases eastern and western stations report the same change in form at nearly the same universal time, sometimes within five minutes. Thus on August 23, 1944, Montreal and North Dakota both report "G" and then "HA" for the same hours. On October 11, both east and west stations report "HA" at one time and "HB" later. On October 15, Ithaca, Sault St. Marie, and Montana all report "RA" at the same time and a fading out of aurora at the same time. On November 6, the east stations reported "HA" and the west reported "HB".

Some form of aurora was noted on 75 days between May 3, 1944, and May 1, 1945, for the Lake-Region of the United States. By three-hour intervals these displays are classified as 74 in class 1, 36 in class 2, 12 in class 3, seven in class 4, three in class 5, two in class 6, and one in class 7. Outstanding displays occurred on August 3 and October 15, 1944, and March 15 and April 12, 1945. Pulsating forms seem to occur at, or just after, a peak in the aurora.

To understand the details of the aurora better we have begun the analysis of our accumulated data by punched-card methods. All the original data have been transcribed to standard sheets so the data can be analyzed by the three-hour K-periods. The cases of no aurora total 1300. They have been analyzed as much as necessary but will be studied more after the cases of aurora have been studied. In 729 cases the observation covered the entire three hours while in an additional 564, two of the three hours were observed. Figure 1 gives these three-hour data. It is clear that the larger K-figures are seldom associated with the absence of aurora since the frequencies B are much less than the natural distribution of K. We note, in instances of higher K-figures, that moonlight was strong and may have obliterated faint aurora. Later comparison with similar charts of aurora versus K will show how effective the moonlight is in outshining the aurora. It is possible that bright moonlight actually suppresses the aurora.

In cooperation with Dr. H. P. GAGE of the Corning Glass Works we have developed a set of filters which are very useful in visual observation. The characteristics of the filters are set forth in Figure 2. The green filter consists of three parts, two of which can be moved aside to permit use of the yellow-glass component alone. The green filter shows aurora in moonlight and twilight when it is otherwise invisible. In fact the aurora stands out as by magic. In cloudy weather aurora is present whenever the green filter appears brighter than the blue or orange. The yellow filter alone is nearly as good except in strong moonlight. The filter has enabled the detection of aurora in fading twilight 10 to 20 minutes before it is visible without the filter. This enables all the apparatus to be put into operation early in the evening. The filters are so helpful one wonders how he worked without them. The filters are also useful in studying the color-distribution in the aurora after it is detected. When auroral light appears through a given filter, we can say almost certainly which spectrum-line is present even though it is so faint as to appear uncolored. This is most important as one is then studying the processes of ionization and excitation which produce the light. The following statements are given as tentative:

The glow usually has the red relatively strong and when it looks "alive" the green has begun to strengthen. Even relatively bright arcs show little blue. After rays form they become blue at the top with the red and green in the lower part, almost as distinct sets of rays placed end to end. Some of the above are known from spectrograms but the filters allow one to examine each individual part.

The filters are sometimes not better than a very good direct-vision spectroscope but are far more useful in general.

The photoelectric apparatus has given several additional peaked records, where the peak corresponded with a decrease in the horizontal component of the Earth's magnetic field. An attempt is being made to find if any single wave-length is responsible for this increased brightness. That might give a clue to the current-carriers of the magnetic disturbance-current.

It is planned to set up three additional photoelectric recorders, one at Ithaca, another at Milwaukee, and a third possibly in Canada.

The new photo-multiplier 931A has been tried and gives about a hundred-fold increase in sensitivity. The still better number 1P21 tube has been purchased and will give another three-fold increase. The experimental apparatus has been built and tested and all difficulties seem to be surmounted. The high voltage to the cell must be carefully regulated and leakage-currents mitigated. The final apparatus (see Fig. 3) consists of two number 1P21 cells which see the sky and aurora through a sector-disk and filters. One cell will see a wave-length region containing one of the violet lines while the other cell will see a wave-length region containing no strong auroral line. When the alternating-current output is fed to a balanced differential amplifier no

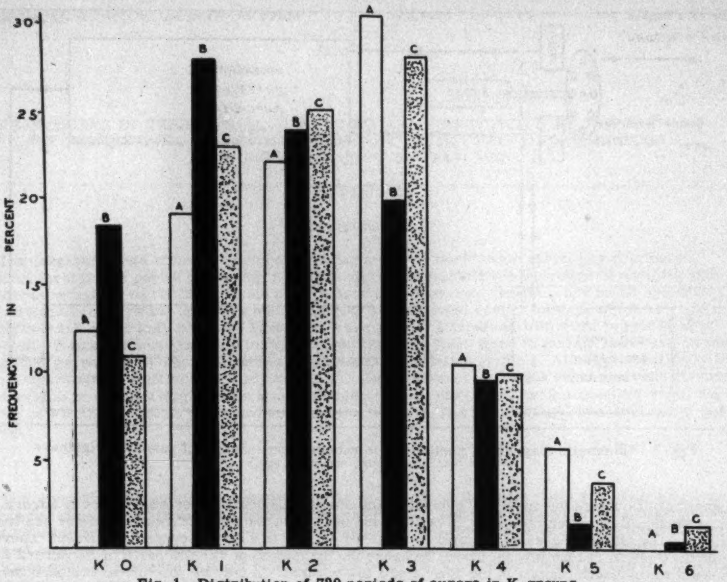

Fig. 1--Distribution of 729 periods of aurora in K-groups
[A = percentage with moonlight 9; B = percentage in a given K-group; C = percentage of moonlight 8 or 9]

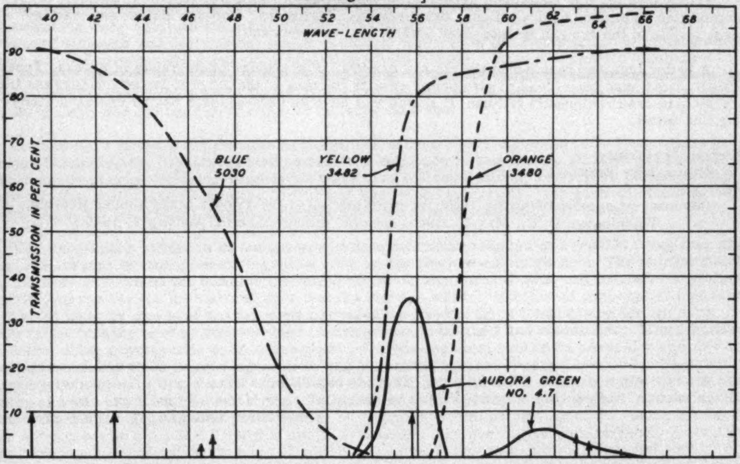

Fig. 2--Characteristic transmission of filters used in auroral observation

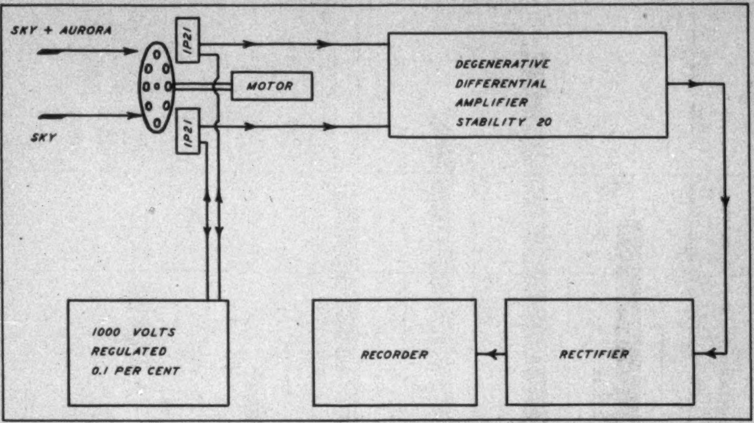

Fig. 3--Schematic diagram of photoelectric recorder for studies of auroral brightness

signal results unless the spectrum balance to the cells is disturbed by the appearance of aurora. This should allow better recording in twilight and moonlight and prevent interference by scattered clouds. The alternating-current output is rectified and put in a direct-current recorder. There appears to be no reason why we cannot measure the brightness of various parts of the aurora in several wave-length regions in the course of a few minutes. It may be possible to compare the upper and the lower ends of a single ray.

Other uses for this equipment appear to be recording of flashes of lightning, possible detection of glow in a cloud before a flash, and recording of meteors. One can almost say that any light visible to the eye can be measured within, say, ten per cent.

A better lens has been put in the all-sky camera. For regular photographs of aurora, Type-103aF plates have been found to give better results because of the auroral bands and because the plates have less reciprocity failure. It seems that modern field-glasses can be useful in studying fine detail.

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RESEARCHES IN TERRESTRIAL MAGNETISM AND ELECTRICITY AT DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, DURING APRIL, 1944, TO MAY, 1945

J. A. Fleming

Introduction

The long-sustained effort required for waging a war of world-wide extent has continued unabated through the period under report and rendered impossible the execution of anything like the normal program of the Department of Terrestrial Magnetism. Military and naval operations, so inimical to geophysical investigations requiring international cooperation, of which terrestrial magnetism and electricity are good examples, have greatly interfered with work in this field of research. It has not been possible to equip expeditions for field-work in foreign lands and on the oceans for providing the much needed data for secular-variation studies. Although practically all of the Department's staff have turned attention to the solution of problems connected with the war, considerable progress along certain lines has been made. Moreover, much important work, the results of which may not be published until the war is over, has been brought to a successful conclusion.

Geomagnetic investigations

The variation with geographic position of the amplitude of the solar daily variation (S_q), particularly for the anomalous regions between the geomagnetic and geographic equators, was mapped utilizing observations of S_q obtained at numerous field-stations as well as at more sparsely distributed magnetic observatories. The amplitude of S_q is greatest near the geomagnetic equator, and its anomalous increase is most marked at the points of the greatest departure of the geomagnetic from the geographic equator.

Theoretical computations of vertical intensity from world-charts of horizontal intensity and magnetic declination were developed and tested using the method of field-analysis by integrals. Relationships were obtained among derived and intrinsic magnetic elements of world-charts in horizontal intensity and declination, useful in certain features of the construction of isomagnetic charts consistent with requirements of electromagnetic theory. Maps of magnetic anomalies in vertical intensity for Pacific areas were constructed. A theoretical examination was made of the problem of adjusting isomagnetic charts to mutual consistency, the definition of the normal geomagnetic field, and intrinsic properties of mapping contours.

Studies were made of the changes in magnitude of short-period geomagnetic fluctuations at various ocean-depths, because of electromagnetic induction in sea-water. Data on geomagnetic effects accompanying lightning-discharges were also collected during a two-year period for the magnetic observatories at Huancayo (Peru) and Watheroo (Australia). The general shielding-effect of sea-water for very rapid magnetic fluctuations was also successfully calculated.

The geographic incidence of aurora and geomagnetic disturbances was studied using data for over 100 auroral stations, observing since 1872, in the Northern Hemisphere. The isochasms of FRITZ were revised on the basis of geomagnetic as well as auroral data, and extended to include quantitative results for the auroral zone and the regions within. Isolines of percentage-frequency of days of visually observed aurora were prepared for the Northern Hemisphere for the days of observation uninfluenced by unfavorable conditions due to daylight and cloudiness. This improved estimate, using geomagnetic data, of the position of the region of maximum auroral frequency was checked and found to be in good agreement with extensive auroral observations of the First and Second International Polar Years 1882-83 and 1932-33, and with those of many expeditions in other years. As was expected, the world-wide incidence of aurora shows a distribution in close agreement with that for geomagnetic disturbance.

Near the center of the auroral zone as in middle latitudes, there is marked parallelism between frequency of days with auroras and sunspot-number; at the auroral zone the frequency of days on which auroras were visually observed is practically independent of sunspot-number, since auroras occur on practically all days, even during minimum of sunspots. Auroral data for the Southern Hemisphere were also compiled, and the position of the southern auroral zone was estimated, using the geomagnetic data of various expeditions.

The hourly percentage-frequency of aurora in the absence of clouds and other conditions unfavorable for observation was derived for some 30 stations. These data, contrary to certain previous findings, when arranged on as strictly intercomparable bases as seems conveniently possible, show a fairly simple pattern for the geographic distribution of characteristics of the diurnal variation of aurora. Lines of equal average hourly percentage-frequency of aurora are being mapped for the Northern Hemisphere for several positions of the Sun relative to the Earth.

From an investigation of the unusual auroral forms observed visually during 1932-33 at Meanook, Canada, it was concluded that long, thin, feeble, homogeneous auroral arcs--previously rarely observed in northern Europe and of which six cases were noted at Meanook--appear most frequently and perhaps always in a region some hundreds of kilometers outside the auroral zone. An arc of this type underwent pulsations in light-intensity of period similar to that of simultaneously recorded geomagnetic pulsations.

Geoelectric investigations

An investigation was made of some aspects of mechanisms proposed to elucidate the generation of charge in thunderstorms. Quantitative examination brings into question essential portions of all the proposals which have not yet been definitely refuted by qualitative evidence.

The electric cycle of the thunderstorm may be regarded as consisting of the following steps: (a) The initial small-scale separation of charge in which individual particles of precipitation and cloud-particles become charged, and, during which ions may possibly be formed in the electrically active center of the storm-cloud; (b) the large-scale separation of charge in which particles or ions charged with electricity of one sign are separated from those of the other sign to distances of several kilometers--this may consist of several steps; (c) the initiation of the lightning-discharge, namely, the mobilization of charges on individual drops, widely distributed throughout some cubic kilometers of space, at such a rate and in sufficient quantity to supply the lightning-discharge proper; (d) the lightning-discharge comprising several identifiable steps which follow the foregoing stage and complete the electric cycle. This last phase of the cycle is now much more clearly elucidated than the other steps. Steps (a), (b), and (c) were the subject of this study, from which the following tentative views were developed: (1) That the initial separation occurs in a region of turbulence between two air-masses or air-cells; (2) that a first stage in a large-scale separation (an intermediate-scale separation) consists of a centrifuge-like action of the eddies in the turbulent region; and (3) that after this intermediate-scale separation, charges of one sign and size are introduced into an air-stream having a velocity which may differ in both magnitude and direction from that into which the particles of opposite sign, and doubtless of different size, have been introduced.

The results of the cooperative project of the Department of Terrestrial Magnetism, the United States Coast and Geodetic Survey, and the Bell Telephone Company for the measurement of earth-currents at Tucson, Arizona, have been reduced and analyzed. The earth-current data from Watheroo and Huancayo have also been brought up to date by reduction of the records from July 1940 to January 1944. The most pronounced feature of the records obtained during this interval at all three observatories is the low activity in earth-current flow characteristic of periods near a sunspot-minimum.

The seasonal variation at Tucson exhibits several unusual features, most strking of which is a large increase in the magnitudes of both components in January. Records from the individual years have shown that the magnitude of the diurnal variation in January is invariably much greater than that in December or in February and is even equal to, or greater than, that in the summer or equinoctial months. At the same time the character of the diurnal variation and its phase-relationship is the same as that for the other winter months. With the data from all 12 winter seasons at Tucson, it is possible to follow this increase in activity over five- or ten-day intervals and it is found to begin near the winter solstice to reach its maximum between January 5 and 10, and to disappear early in February. The cause of this unusual feature is not yet clear, but since a similar phenomenon has been noted in the magnetic variations at Tucson, it is unlikely that it is due to changes in resistivity or to other factors which might affect current-flow alone.

An analysis of the question of the accumulation of radioactive matter in the lower air at College (Alaska) and Huancayo (Peru) was made. In the former place it showed, just as for Watheroo and Washington, the effect of an accumulation of radioactive matter near the ground during the period of the day when the wind is low, and a reduction in the amount of radioactive matter when the wind increases in velocity. At Huancayo, contrary to what was found at College and Watheroo, calm conditions do not favor the production of higher conductivities, but rather the reverse. These results confirm the belief that nuclei are brought down from higher layers to the lower layers.

Tests in measuring the mobility of ions with an ion-counter emphasized the importance of maintaining the central electrode near ground potential. For heavily ionized air the usual measuring equipment must be modified by the use of a resistance of sufficiently low value connected in parallel with the electrometer.

Observatory and field-work

During the past year, the major effort of the Ionospheric Section has been devoted to the practically simultaneous establishment of new ionospheric stations outside the continental United States. The technical crews for each new station were trained as working groups. Operation of the automatic multifrequency-recorders of the Carnegie Institution of Washington was continued at Huancayo, Watheroo, and College. Ionospheric measurements from Huancayo and Watheroo are now continuous for more than half a sunspot-cycle without any significant instrumental changes. These extended series of measurements have been particularly helpful in analyses of long-term trends and in preparation of forecasts of radio-propagation conditions.

Considerable progress has also been made in the improvement of manually operated ionospheric recorders. Promising studies have also been pursued to determine relations between sporadic E, aurora, radio blackouts, and conditions of radio propagation, especially in polar regions.

The extensive geophysical programs at the Huancayo and Watheroo Magnetic Observatories were continued without curtailment. Maintenance of International Magnetic Standard at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey was effected through cooperation with the Division of Geomagnetism and Seismology of the Survey.

No new field-work could be undertaken by the Department other than at the observatories. It was found possible, however, by loans of magnetic instruments to assist various Governments to undertake new surveys and to reoccupy repeat-stations.

Publications

Additional volumes of the quarto publications entitled "Scientific results of Cruise VII of the Carnegie during 1928-1929 under command of Captain J. P. Ault" have appeared: These are Biology V, Chemistry I, Oceanography IA, and Oceanography II. Oceanography IB is in the hands of the printer and the preparation of Oceanography III and IV is well advanced.

A few of the principal papers published during the year are listed below:

A. BERNSTEIN, A survey of methods of constructing magnetic charts, Terr. Mag., v. 49, pp. 169-180, 1944.

E. H. BRAMHALL, Auroral photogrammetry, Amer. Geophys. Union, Trans. of 1944, pp. 592-598, 1945.

N. DAVIDS, Calculation of vertical component (Z) for potential fields from observed values of declination (D) and horizontal intensity (H), Terr. Mag., v. 49, pp. 245-250, 1944.

J. A. FLEMING and W. E. SCOTT, List of geomagnetic observatories and thesaurus of values, Terr. Mag., v. 49, pp. 109-118, 199-205, 267-269, 1944.

O. H. GISH, On Theories regarding some electrical aspects of thunderstorms, Amer. Geophys. Union, Trans. of 1944, pp. 571-575, 1945.

H. D. HARRADON, Some early contributions to the history of geomagnetism--VII and VIII, Terr. Mag., v. 49, pp. 185-198, 1944; v. 50, pp. 63-68, 1945.

M. W. JONES and A. A. GIESECKE, Atmospheric-electric observations at Huancayo, Peru, during the solar eclipse, January 25, 1944, Terr. Mag., v. 49, pp. 119-122, 1944.

A. G. McNISH, Changes in the solar-diurnal variations in vertical magnetic intensity at the Huancayo Magnetic Observatory, 1922-43, Amer. Geophys. Union, Trans. of 1944, pp. 560-571, 1945.

W. J. ROONEY, Summary of earth-currents records from Tucson, Arizona, for a complete sunspot-cycle, Terr. Mag., v. 49, pp. 147-157, 1944.

J. H. TAYLOR, On the determination of magnetic vertical intensity, Z, by means of surface integrals, Terr. Mag., v. 49, pp. 223-237, 1944.

E. H. VESTINE and N. DAVIDS, Analysis and interpretation of geomagnetic anomalies, Terr. Mag., v. 50, pp. 1-36, 1945.

E. H. VESTINE, The geographic incidence of aurora and magnetic disturbance, Northern Hemisphere, Terr. Mag., v. 49, pp. 77-102, 1944.

F. WENNER, The oersted and the gauss, Amer. Geophys. Union, Trans. of 1944, pp. 598-599, 1945.

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REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

(See also pp. 18, 58, 68, and 90)

I. S. GELFAND: Direct and inverse problem of the magnetic potential for a spheric segment. Bull. Acad. Sci., U. S. S. R., Sér. Géog. Géophys., v. 8, no. 5, pp. 292-294, 1944.

In this paper there are given formulas for the magnetic potential and the components of the magnetic force in the underground strata. These formulas have the form of a spheric segment in the case of a uniform and direct magnetization.

A method, based on the solution of the direct problem, is suggested for the determination of the stratum of the spheric segment using the observed values of horizontal and vertical components of the magnetic force at a known intensity of magnetization of rocks.

English summary by author

V. V. FEDYNSKY: Geophysical prospecting for oil in the U. S. S. R. at the time of Patriotic War (1941-1943). Bull. Acad. Sci., U. S. S. R., Sér. Géog. Géophys., v. 8, no. 5, pp. 229-243, 1944.

The State oil-industry of the U. S. S. R. had, at the beginning of World War II, a centralized service of geophysical prospecting. The Geophysical Trust of the People's Commissary of Oil Industry assigned numerous prospecting parties to the task of locating oil-reserves. The war demanded a rapid increase in production of oil in the eastern regions of U. S. S. R. Geophysical work aided greatly in this. From 1941 to 1943 the work of prospecting increased one and one-half times. Seismic prospecting (44 per cent), electrical prospecting (28 per cent), gravity-methods (24 per cent), and others were used. Well-investigations were widely made.

Large areas in the region of the salt-domes in the Emba-River Basin (northeastern part of the Caspian shore) were covered by seismic prospecting. Excellent results were obtained on salt-domes and other structures. Work along the Caspian Sea near Baku was carried out by the reflected-wave method, which was applied for the first time in 1941 and used with much success in 1942 and 1943. Seismic prospecting in the oil-fields in Turkmenia (southeastern Caspian shore), situated in the desert, were carried out by explosions on the surface because of lack of heavy transport.

Large areas east of the European part of the U. S. S. R. were covered by electrical surveys. In the regions of the Middle Volga, extending to the west of the Ural Mountains, electrical prospecting was used in connection with gravimetry. The method of continual current was chiefly applied. Distances up to 20 km were used between the feeding electrodes. The methods of geological interpretation of the results of electrical prospecting were improved greatly.

The gravimetric surveying was carried out with gravimeters and torsion-balances. There was a lack of gravimeters so the torsion-balances were chiefly used. Work was also done in Bashkiria (west slope of the Ural Mountains) where electrical prospecting in connection with gravimetry was used to find a series of new oil-structures.

Magnetic surveying was used for the study of the general structure of some regions.

Geophysical prospecting for oil-fields in the U. S. S. R. in the years of World War II played an important part in the general war effort of the Soviet Union. Geophysical prospecting for oil in the U. S. S. R. will tend to expand in order to satisfy important demands of defense and the national economy.

English summary by author

Transactions, American Geophysical Union Volume 26, Part I August, 1945

RESEARCH WITHIN PHYSICAL OCEANOGRAPHY AND SUBMARINE GEOLOGY AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY DURING APRIL, 1944, TO APRIL, 1945

H. U. Sverdrup and Staff

(Contribution from the Scripps Institution of Oceanography, New Series, No. 270)

Participation of members of the staff in war work has continued and has been further expanded. The nature of the work is such that as yet no report can be given to the American Geophysical Union.

G. F. McEWEN has completed the revision of certain preliminary basic mathematical tables required for further researches on evaporation and mixing, and a limited number of photostatic copies are on file. The tables are as follows:

(A) Table of e^{-x^2}, carried to six decimal places at intervals of 0.001 within range for x from 0 to 2.50, and of 0.01 within range 2.50 to 3.30.

(B) Table of $\left(\frac{e^{-x^2}}{x}\right)$ and $\int_x^{\infty}\left(\frac{e^{-x^2}}{x}\right)dx$, carried to six decimal places at intervals of 0.001 within range for x from 0 to 2.50 and of 0.01 within range 2.50 to 3.30.

(C) Table of $P_0(z) = \int_{0.001}^{z}\left[\int_z^{\infty}\left(\frac{e^{-x^2}}{x}\right)dx\right]dz$, carried to six decimal places at intervals of 0.001 within range for z from 0.001 to 0.500, and of 0.01 within range 0.500 to 3.000.

(Note: $P_0(3)$ differs only one in the sixth place from the limiting value.)

(D) Tables of $\int_x^{\infty}\left(\frac{e^{-x^2}}{x-c}\right)dx$ and $\int_x^{\infty}\left[\frac{e^{-x^2}}{x(x-c)}\right]dx$, carried to four decimal places at intervals of 0.05 within range for c from 0 to 3.15 and of 0.01 within range for x from $(c+0.01)$ to $(c+0.20)$.

These two integrals, each of which required double-entry tabulation with respect to both x and c for $c = 0$, were particularly difficult to evaluate and required the formulation of various special devices, depending upon the values of x and c, in order to obtain the required accuracy of four decimals. The range of values probably includes those most likely to be needed in proposed applications to the problems of evaporation and mixing, and covers the field most difficult to compute. Since it was first necessary to compute the integrals

$$\int_x^{\infty}\left(\frac{e^{-x^2}}{x+c}\right)dx \qquad \text{and} \qquad \int_x^{\infty}\left[\frac{e^{-x^2}}{x(x+c)}\right]dx$$

it is the intention to prepare copies of these tabulations as well, in order to save the results for possible use later.

From Table B, as indicated above, Table 2 of McEWEN'S Distribution of temperature and salinity [see 1 of "Reference" at end of paper], can readily be revised as may be required for application to either fresh water, sea water, or the atmosphere.

Preparatory to proposed studies of the vertical distribution of temperature and humidity, attempts have been made to fit empirically certain simple mathematical formulas to data already published. A simple hyperbolic law has been found to apply quite accurately in many cases, this facilitating the computation of gradients and the development of theories of vertical distribution.

In August, 1944, work on the above tabulations was interrupted in order to develop further the solution of the problem of the horizontal dispersion of material from an initial source, circular in form. This problem arose in connection with studies on the distribution of fish eggs and larvae in the ocean. The solution obtained early in 1944 was subject to certain limitations in the range of values and involved an error of about one per cent. Further researches in the problem were undertaken because of unexpected applications in another field involved in a war project. Important improvements were worked out in response to an urgent request and a complete solution of greater accuracy was finally obtained. One final step in the solution proved particularly difficult, that of evaluating

$$\int_{x_1}^{x_2} \left(\frac{e^{-x^2}}{\sqrt{a+x}}\right) dx \qquad \text{and} \qquad \int_{x_1}^{x_2} \sqrt{a+x}\ \ e^{-x^2}\, dx$$

Solutions of these integrals, adapted to theoretical interpretation and to methods of numerical evaluation, have been completed.

In view of the progress made in dealing with the various mathematical problems, apparently separate and disconnected, attention can now be directed mainly toward obtaining unified results with emphasis on the physical aspects required in certain researches on the ocean and atmosphere.

The usual observations of temperature, salinity, and weather at our six stations on shore and supplementary observations from United States Lighthouse tenders have continued. There were about 1,800 observations of salinity and sea-temperature, and 1,500 observations of wind. Barograph-recording, pyrheliometer-records, and daily observations of humidity and precipitation were continued.

Reference

[1] G. F. McEWEN, Bull. Scripps Inst. Oceanography, 1929, pp. 268-278.

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University of California,
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(Manuscript received April 23, 1945, for presentation at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until January 1, 1946.)

NOTES AND PERSONALIA

NOTES

(See also pp. 11, 12, 27, 32, 36, and 82)

Corrigenda--The following changes and errors have been noted in the Transactions of 1944:

Part II, p. 330, Section of Geodesy, W. D. Lambert, Secretary (1925-1931) should read (1925-1929). In 1929 Lambert was made President for a three-year term and H. G. Avers was named to serve his unexpired term as Secretary (1929-1931).

Part III, p. 339, the references [4] to [9] and the sources of data [a] to [e] are misplaced and should have appeared at the end of Edgar E. Foster's article on p. 405, the references being numbered [1] to [6].

Part III, p. 400, paragraph 4, line 6, should read "This point would be equivalent to approximately -18.°0 C."; p. 401, paragraph 1, formulas should read $P/E = 11.5[P/(T - 10)]^{10/9}$ and $I = \sum_{n=0}^{n=12} 115[P/(T - 10)]^{10/9}$; paragraph 3, entry against Name, Symbol C, should read "Subhumid,"; and paragraph 4, entries against Name, Symbol B′ and C′, should read "Mesothermal" and "Microthermal," respectively. (It is to be noted that these corrigenda do not affect the climatic groups or the data on p. 402 from which they were plotted.)

Part IV, p. 541, the name of author, namely, H. H. Howe, should appear below the title of the paper "Analysis of magnetometer-deflections."

Part V, p. 737, paragraph 4, line 14, should read "Freehold, New Jersey," not "Freehold, Missouri."

Transactions, American Geophysical Union Volume 26, Part I August, 1945

OCEANOGRAPHIC INTERESTS AND ACTIVITIES OF THE COAST GUARD

R. R. Waesche

The Coast Guard is maintaining continued interest in oceanography especially as it may have practical application to problems related to ice-patrol, air-sea rescue, and other duties with which the service is charged. Ocean-currents and wind-drift affect the movement of ice, life-boats, and of airplanes and rubber boats from airplanes forced down at sea. The state of the sea as indicated by size and character of waves determines largely whether or not a rescue plane can make a successful water-landing and take-off. The amount of surf on a beach caused by waves and swells is a controlling factor in the launching and landing of small craft, long a vital interest of the Coast Guard. Much remains to be learned about the icing of a vessel's superstructure at sea and of means of avoiding and combating this condition. Corrosion and fouling are an ever-present problem wherever vessels and buoys constructed of metal are concerned. Increased air-traffic over the ocean-areas has introduced new problems in both oceanography and meteorology. In many respects these sciences are closely interwoven. Oceanic circulation involves large masses of water transporting heat from place to place on the Earth's surface, greatly influencing world climate. Any factors upsetting the normal heat-transport will be reflected in some form and degree in future weather-sequences. For example, indications are strong that an abnormal extent of ice in the North Atlantic, resulting in lowered water-temperatures and less evaporation, reduces during a succeeding period the precipitation in western Europe. It is believed that weather-patrol ships on station in the interests of cross-ocean aviation will be in a position to contribute much oceanographic information of value. A close check of temperatures and salinities for prolonged periods can be kept to indicate variations both in volume of flow of the major currents and of attendant heat-transport.

The active oceanographic work formerly conducted by the Coast Guard in connection with the International Ice Patrol has been curtailed during the war years because of the shortage of vessels and personnel. An Ice Information Service and a modified form of ice-patrol have been maintained, however. Aircraft have played an increasingly important part in ice-scouting. As compared with surface vessels, planes can cover a large area more quickly. Areas not navigable by ships can be scouted from the air, thus obtaining an estimate of the amount of ice upstream from critical lanes of navigation. The state of ice in closed areas can be closely watched in order to predict the date of break-up. The forming of new ice can be followed. Planes are a valuable aid to ships in ice-piloting, as the navigable and blind leads can be spotted and the ship informed of the proper courses to steer. On the other hand, ships can better judge the character of the ice, are less vulnerable to bad weather, and normally benefit by more precise navigation.

A careful record has been kept of the ice-movements during the war years. Areas of little concern in peacetime have come under close surveillance and in many respects a better overall picture of the ice-conditions in the North Atlantic Ocean and contiguous waters has been obtained. Comprehensive reports have been prepared for the years 1942 to 1944. Much of this material is of such a nature that it probably can be released at the conclusion of the war. Of prime importance to trans-Atlantic shipping and the major concern of the International Ice Patrol in peacetime are ice-conditions on the Grand Banks of Newfoundland and adjoining waters. For those interested in following ice-conditions in that area from year to year, a brief summary is given here covering the past three seasons.

The year 1942 was the third consecutive year in which few or no icebergs reached the Grand Banks Area. The lightness of the berg-crop is emphasized by comparing the estimated 30 bergs in 1942 to the average number, 428 per year, that drifted south of the 48th parallel during the 41-year period from 1900 to 1940. The only previous sequence this century of three comparably light-ice years was that of 1900 to 1902. The bergs reported south of latitude 48° north in 1942 were all within 75 miles of the east coast of the Avalon Peninsula with most of them along or within 20 miles of the beach. No bergs whatsoever were reported in the main branch of the Labrador Current following the eastern edge of the Grand Banks. Although it is quite possible that a few may have slipped down this route under the cover of the prevailing fog, none was sighted in upstream positions favoring that drift. The crop of pack-ice was correspondingly light. Scattered patches only were reported south to the latitude of St. John's, Newfoundland, and at no time did the ice seriously threaten to close that harbor. Pack-ice was not reported in the main branch of the Labrador Current along the eastern edge of the Grand Banks at any time during the season. Trans-oceanic shipping routed south of Newfoundland was entirely free of this hazard.

The season 1943 ended the sequence of abnormally light ice-crops that had begun in the year 1940. Both icebergs and pack-ice were somewhat more abundant than normal. Bergs appeared in numbers in the pack east of Newfoundland in March but none was reported at positions south of the 47th parallel prior to May. The early season was characterized by a release of bergs along the eastern edge of the pack roughly between positions of latitude 49° north, longitude 49° west, and latitude 52° 30' north, longitude 51° west. These drifted eastward at latitudes north of Flemish Cape. It was not until the accelerated break-up of the pack in May that many were released from its southern border to spread farther south over the Grand Banks. None drifted beyond latitude 46° north in the main stream of the Labrador Current until May 11, nor in the inshore branch past St. John's until May 25. The peak of the season occurred early in June and at that time hundreds were scattered throughout the Banks Area to the 42nd parallel. This abnormally late date for the peak, which usually occurs during May, reflects the retarded release of bergs from the southern edge of the pack. Bergs continued to drift south along the east coast of the Avalon Peninsula until August. An accurate estimate of the number of bergs crossing the 48th parallel during the season is difficult because of the numerous sources and varied nature of the reports received but was probably well in excess of 600.

Sea-ice formed locally from time to time off the east coast of Newfoundland south to Cape Race but was rather light. Heavy pack-ice in the main branch of the Labrador Current reached its greatest extension on March 21,at which time patches reached a position of approximately latitude 47° north, longitude 47° west, with the terminus of the field proper about 25 miles to the northwest. Heavy ice drifted to this general locality on occasion throughout most of April.

During 1944 a minimum of 700 bergs are estimated to have drifted south of latitude 48° north. On a single day, April fifth, 140 were observed south of that latitude with perhaps an additional 60 not sighted. The peak of the season occurred in late April or early May, somewhat earlier than usual and at least a month earlier than in 1943. The southward drift continued through July but no bergs were sighted south of the latitude of St. John's after that month. During the course of the season a total of approximately 8,000 sightings, or reports of sightings, were made or received for the area from Grand Banks to Labrador. The distribution approximated that for a normal year.

Pack-ice in 1944 was troublesome more from the standpoint of distribution than from abnormal amount. The ice formed later than usual because of the relatively high temperatures of fall and early winter. It closed the port of St. John's for five days at the end of February when practically all of the ice in that locality was blown inshore to form a coastal belt averaging less than a mile wide. In early April a narrow tongue of heavy ice extended along the eastern edge of the Grand Banks to block east-west routes south past latitude 45° north. This ice receded rapidly, however, and by the end of the month none remained south of the 47th parallel.

An interesting comparison was made of the relative rates of advance of bergs and pack along the northern shoulder of the Grand Banks during March. The bergs averaged 45 miles per day for a three-day period followed by a rate of 35 miles for the next three days. During these same periods the outer edge of the pack in which the bergs were drifting advanced at 35 and 20 miles per day, respectively. Part of this apparent difference in drift-rate arises from the wasting of the pack-ice which is especially rapid at its outer border. The wake of open water frequently observed in the lee of a berg in an ice-field is evidence,however, of the actual difference in drift-rate. The movement of bergs owing to their great draught is predominantly determined by subsurface currents, but that of field-ice by surface currents and winds.

Although no oceanographic work nor current surveys have been made during the war years, the general knowledge of currents obtained during previous years of the International Ice Patrol has been a valuable aid in predicting the ice-movements. Certain technologic developments arising during the course of the war are expected to affect considerably the post-war ice-patrol operations. New and improved air-facilities now available promise to increase the efficiency of ice-scouting. It is presumed that an active oceanographic program will again be resumed upon cessation of hostilities. The extent of this program is difficult to define but the ice-problem will still be present, at least for some time to come.

U. S. Coast Guard,
Washington, D. C.

(Manuscript received May 8, 1945, for presentation at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until January 1, 1946.)

Transactions, American Geophysical Union Volume 26, Part I August, 1945

A REPORT ON THE UNITED STATES COMMITTEE FOR THE STUDY OF THE PARICUTIN VOLCANO

Richard E. Fuller

By necessity this report in a number of respects is identical to one that had to be submitted to the National Research Council on April 15, 1945, but it is appropriate to be repeated here, for the initial conception of the Committee and its potential function were formulated at the last Annual Meeting of the Section of Volcanology, when a symposium was presented on the activity of Parícutin. The retiring officers then recommended to WILLIAM W. RUBEY, the Chairman of the Division of Geology and Geography of the National Research Council, that a Committee should be formed to integrate, facilitate, and stimulate the study of the eruption and its effect in various fields of science before the record was lost. As the newly elected President of the Section, RICHARD E. FULLER accepted the responsibility of serving as Chairman.

Before the Committee was formally approved by the Executive Committee of the Division on July 31, 1944, a wire from ROSS G. HARRISON, Chairman of the National Research Council, to MANUEL SANDOVAL-VALLARTA, President of the Comisión Impulsora y Coördinadora de la Investigación Científica, and a letter from WILLIAM F. FOSHAG to EZEQUIEL ORDOÑEZ, Chief Geologist of that organization, resulted in the assurance that a corresponding Mexican Committee would be formed to cooperate in this work. The official invitation from the Secretary of Foreign Affairs of the Mexican Government was received by our State Department on September 8, 1944. In the meantime Chairman FULLER visited the volcano with FOSHAG to become somewhat familiar with the field.

Projects--The initial objectives of the Committee were defined during a round-table discussion at which many of those interested were present, and subsequently by an informal meeting prior to official ratification. Plans were further crystallized in three meetings of the Committee during later months. Some progress has been made towards the attainment of all major objectives then defined, in spite of the difficulty imposed by the manpower situation.

In October, through the cooperation of the Interdepartmental Committee on Cultural and Scientific Cooperation for the Department of State, the United States Geological Survey received approval and financial support for a project involving the topographic mapping of the volcano and the adjacent region by KENNETH SEGERSTROM and the geologic mapping and study of the region surrounding the mountain by HOWEL WILLIAMS during an eight months' assignment. In January that same Committee of the State Department enabled the United States Coast and Geodetic Survey to initiate a project for magnetic and seismological observations at the volcano under AUSTIN E. JONES. In defining the project they had the assistance of A. G. McNISH of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

At the meeting of the Committee in November, at which HOWEL WILLIAMS presided, immediately prior to his departure for Mexico, a motion by L. C. GRATON resulted in the submission to the Geological Society of America of an application for a grant of $2,500 for construction and maintenance of physical improvements. With the cooperation of McNISH and GRATON, the Chairman applied for these funds and also for an additional sum of $7,500 to be earmarked for potential projects. In response, the Geological Society of America most generously granted the sum requested and earmarked $15,000 for projects to be approved by the Committee and the Project and Executive Committees of the Society. From this fund, the Chairman has been granted $1,750 for an aerial survey and $1,100 for a gravity-survey involving the service of FREDERICK ROMBERG of Austin, Texas, and VIRGIL E. BARNES of the University of Texas. For this project, ROMBERG generously contributed both his time and the use of a LaCOSTE and ROMBERG gravimeter.

The Committee was also successful in obtaining the service of E. G. ZIES through the cooperation of the Geophysical Laboratory of the Carnegie Institution of Washington. ZIES visited Parícutin during November and December with FOSHAG, ORDOÑEZ, and WILLIAMS, to become familiar with the terrain so that he could be better equipped to serve as a counsellor. The Committee also assisted in obtaining from Princeton University the service of ERLING DORF, Professor of Paleobotany, for the study of the incorporation of vegetation in the ash. A seismic survey by reflective and refractive methods by Father DANIEL LINEHAN with the cooperation of the Humble Oil Company was considered, but abandoned by unanimous consent as impracticable. Likewise a suggested project intended to determine the heat conductivity of rock was deemed unfeasible.

With the personal authority of the Chairman, FREDERICK H. POUGH, of the American Museum of Natural History, has made a compilation of dated photographs of the eruption at the expense of both the museum and O. O. FISHER. FISHER has also been responsible for having copies made of some of the most important moving pictures, and has also offered to have 4- by 5-inch black and white negatives and prints made for the record from any important kodachrome slides lent him for that purpose.

In the field of biology, which is represented on the Committee by ROBERT T. HATT, we have the cooperation of three scientists who have previously worked in that region. WILLIS A. EGGLER, with the recommendation of the Chairman, received a grant from the American Philosophical Society for the study of plant ecology adjacent to Parícutin, while the University of Michigan is represented by W. H. BURT, who is now continuing studies initiated with HATT on mammalian ecology, and by NORMAN HARTWEG, who has been making a similar study of reptiles and amphibians.

Physical facilities--In the early autumn funds privately donated to the Comisión Impulsora were matched by that organization for the construction of some physical improvements, the most essential of which was the construction of a horse trail across a neck in the San Juan Flow to permit convenient access to the upper casita. This fund also permitted the construction of a small cabin on the northwest side of the lava-field. It is planned that the remainder be used for the construction of a shelter on the south side of the lava-field and a trail leading to it, and also for the erection of a plank bridge across one arroyo in danger of obstructing summer traffic on the main road.

Later a fund of $700 contributed by O. O. FISHER was accepted by FOSHAG in the name of the Committee to cover, among other things, the expense involved in the moving and construction, with improvements, of the upper casita previously donated by the Instituto Geológica, to prevent its destruction by the advancing lava. GRATON also contributed both time and funds towards the construction of a small essential cabin at San Juan Parangaricutiro.

The grant from the Geological Society of America permitted the construction of a permanent headquarters near this site at the end of the road about an hour and a quarter by trail from the upper casita. This house, which is built of asbestos-cement panels, gives adequate accommodation for visiting scientists and for the storage of their equipment where it will not be subject either to leakage or dust. It has a well-equipped kitchen with an oil stove, cots and bedding for seven, and adequate space for a number of other visitors. In addition a fund has been set aside to permit the employment of CELEDONIO GUTIÉRREZ as caretaker, helper, and observer during the next eight months.

Aerial survey--At least until recently the aerial survey authorized by the Geological Society of America has not been possible owing to clouds, the sporadic heavy dust-column, and the fact that the middle of the day, when satisfactory aerial photographs must be taken, coincided with the daily dust-storm. After a shower in the middle of April an attempt by the Compañia Aerofoto Mexicana was thwarted by a heavy explosion. On my recent visit a heavy rain justified another attempt which encountered success on May 29, 1945. By good fortune the only part of the Parícutin region then obscured by cloud was covered excellently in the flight during April and thus permits the construction of a mosaic and a photometric map which can be compared with the fine aerial survey made over ten years ago by the same company for the Mexican Department of Agriculture.

In the meantime the topographic control established by SEGERSTROM has been turned over to the Oficina de Geografía, which is well equipped to prepare a multiplex map under the direction of MANUEL MEDINA. Some progress has already been made by that organization towards the preparation of a map of Parícutin using aerial photographs taken by the Mexican Army in November when atmospheric conditions were far from ideal in spite of the fact that the fliers had waited a month for the opportunity.

Field-work--During the autumn, when, owing to illness and other contingencies, neither FOSHAG nor ORDOÑEZ was available, the initial stage of a notable period of activity was observed and mapped by FRED M. BULLARD under a previous grant from the Geological Society of America and by L. C. GRATON. The later stage of this activity was fortunately observed by FOSHAG, WILLIAMS, and ZIES, who made some very important temperature-measurements with a thermocouple to increase the degree of accuracy that we had been able to attain with two optical pyrometers which the Committee had been lent, one by the United States Bureau of Standards. O. O. FISHER at the same time took some excellent aerial photographs.

To permit greater concentration on the study of his extensive collection of material which is of unique importance in recording the geochemistry of the early activity of the mountain, FOSHAG has announced that his official history of the eruption terminates on February 20, 1945, at the close of the second year. He intends to prepare the manuscript in collaboration with JENARO GONZÁLEZ.

ORDOÑEZ, however, was able to observe some of the renewed activity during the winter and spring months. These flows, before being masked by dust, were fortunately mapped and sampled by WILLIAMS, who was devoting his major time to the completion of his assignment of mapping the surrounding region. For the latter part of April and the first two weeks of May, however, he was able to give his full time to Parícutin when the volcano was having some very active spasms. Unfortunately, scholastic commitments and the need of becoming familiar with some of the collections in Mexico City have caused the termination of his field-work. In the meantime, the activity is being periodically observed by ORDOÑEZ with the assistance of CELEDONIO GUTIÉRREZ, who is employed by our Committee through the Geological Society of America fund. The Committee, however, owing to wartime demands, has not been successful in obtaining the service of a permanent trained scientific observer to assure a continuous record of volcanic activity.

The magnetic and seismic project of the Coast and Geodetic Survey was established in February by AUSTIN E. JONES with the assistance of FRED KELLER, Jr., and is still being continued. The base-station is near the camp at San Juan Parangaricutiro. From there, a series of magnetic stations are observed in a weekly survey. The relative gravity was determined at these points by ROMBERG and BARNES, as well as at the available topographic control-points established by SEGERSTROM, and a number of other points that appeared critical. Owing to the shortage of personnel both in the United States Geological Survey and in the Oficina de Geografía, the Chairman has not yet the assurance that these stations will be accurately located before they are obliterated by wind and rain and deposition of ash.

Thanks to the initiative of GRATON, the Committee during the coming month is sponsoring a helicopter under the United States Army for the observation of Parícutin and the test of the plane. With the cooperation of L. B. HARRISON of the United States Weather Bureau and O. H. GISH of the Department of Terrestrial Magnetism, we hope to establish a project this summer at the volcano for the study of lightning. The Geological Society of America fund is potentially available for this purpose. To take advantage of the great erosion which occurs during the rainy season we also hope to obtain the services of an experienced hydrologist to study the mechanics of aqueous transportation, also through the sponsorship of the Geological Society of America. This report immediately precedes a meeting of the Committee at which it is believed that some of the points in doubt will be solved.

The Committee is composed of:

Richard E. Fuller, Chairman

Fred M. Bullard
O. O. Fisher
W. F. Foshag
L. C. Graton
Robert T. Hatt

D. F. Hewett
A. G. McNish
Ezequiel Ordoñez
W. W. Rubey (ex-officio)
Paul A. Smith

O. W. Swainson
C. Warren Thornthwaite
Francis G. Wells
Howel Williams
E. G. Zies

University of Washington,
Seattle, Washington

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Transactions, American Geophysical Union Volume 26, Part I August, 1945

LETTERS TO EDITOR

ACCURACY OF FORECASTS OF RUNOFF FOR COLUMBIA, KOOTENAY, AND OKANAGAN BASINS AND THE COASTAL BELT ADJACENT TO VANCOUVER FOR 1944

Snow-surveying in British Columbia began in 1935 under the direction of the Comptroller of Water Rights and gradually expanded until 1940, since which time no great extension has been made. The surveys are concentrated in the Columbia (Canada) Basin and a few other interior and coastal areas. Data pertaining to snow-measurements and forecasts of runoff are provided by field-surveys of the Water Rights Branch and from records of the Meteorological Service of Canada and figures for runoff as supplied by the Dominion Water and Power Bureau. The Columbia-Basin surveys are carried on jointly with authorities of the United States. The work covers the entire Columbia River Area from the river's source in Canada to its mouth at the State-line between Oregon and Washington.

The forecast of 1944 [see Trans. Amer. Geophys. Union, pp. 103-107 and 182, Pt. I, 1944, for information concerning 1942 and 1943--map of snow-survey system and stations appears on p. 182] from the water-content of the snow-cover at the end of March was reflected with varying degrees of accuracy in the runoff of the summer months. Before going into details, a line or two as to the method used leading to the forecast may be of interest.

Each year at the end of March the water-content of the snow-cover of a watershed is measured and the accumulation computed for a given number of years. The cumulative runoff in acre-feet from this watershed from say April to August is then found for the same number of years. From these findings there evolves a snow-course water-content normal in terms of runoff.

The average water-content of the snow-cover for any particular year is expressed in per cent of the snow-course normal, and the product of this percentage and the normal runoff in acre-feet will give the forecast.

Accuracy depends on how near to normal is the rainfall during the season of runoff, the moisture-condition of the soil, the frozen or unfrozen condition of the ground-surface beneath the snow-cover, premature runoff from beneath the snow-cover, and occasional climatic changes such as midwinter thaws. However a fair percentage of the years are more nearly normal than otherwise, and when such is the case the forecasts will compare favorably with the actual runoff. [Information on snow-surveying in all its phases may be found in U. S. Dep. Agric. Misc. Pub. 380.]

At the end of March, 1944, over the greater part of the snow-survey area, the water-content of the snow was less than average. This condition, not being balanced by an above-normal spring and summer rainfall, resulted in lower reservoir-levels with a consequent less amount of water for irrigation and power. The East Kootenay snow-cover was deficient in water-content by one-half the usual amount, the Okanagan slightly above normal, while on the Coast the deficiency was 90 per cent of normal.

Table 1 shows the spring and summer values of precipitation and temperature. The precipitation during the summer runoff-period for the Kootenay-Columbia Basin averaged 102 per cent of normal. Although the basin as a whole had above-normal precipitation, large areas were deficient, which condition, however, improved during July and August. The Coastal and Okanagan areas had, during the spring and summer periods, a respective rainfall of 77 per cent and 172 per cent of normal.

Table 2 shows a comparison of the forecast for the runoff with the actual runoff. From the watershed of Powell Lake, for example, the forecast was too high by 45 per cent. This prediction was made on the assumption that rainfall during the period of runoff would be close to normal. However, the rainfall was but 69 per cent of normal. The deficiency was the chief reason for the divergence of the forecast from the actual. In the Vancouver and Stave-Lake areas the snow at lower elevations had disappeared by the end of March; consequently no forecasts were made. In these areas three coastal rivers flowed 68, 58, and 52 per cent of normal from April 1 to July 31. The precipitation for the same period was 83 per cent of normal. Coastal temperatures were less than 1° above normal.

The runoff of the following streams from April 1 to August 31 was forecast as follows:

Elk River and Kootenay River (at Wardner) 48 per cent of normal, being lower than the actual by 13 per cent; Lardeau and Duncan rivers 75 per cent of normal, being within two per cent of the actual; Kootenay River at Glade 74 per cent of normal, actual runoff not known owing to construction of hydroelectric-power dam.

Table 1--Precipitation and temperature in percentage of normal, 1944

Station	Precipitation		Temperature		
	Normal	Pct normal	Normal	Pct normal	Diff. normal
	in		°F		°F
April to July, 1944					
Coastal					
Powell River	7.24	71	57	102	+1
Lois River	11.77	67	. .	. . .	. . .
Stillwater	9.18	64	. .	. . .	. . .
Capilano	20.19	64	. .	. . .	. . .
Alouette Lake	19.67	92	. .	. . .	. . .
Vancouver	. . . .	. . .	57	102	+1
Stave Falls	15.98	104	57	102	+1
Stave Lake	27.95	74	57	96	-2
Agassiz	. . . .	. . .	58	100	0
Hope	. . . .	. . .	59	100	0
Interior					
McCulloch	8.66	146	48	98	-1
Osprey Lake	5.27	199	50	98	-1
April to August, 1944					
Interior					
Field	9.59	120	. .	. . .	. . .
Glacier	13.37	125	49	102	+1
Cranberry Lake	6.48	133	54	100	0
Revelstoke	9.49	83	58	107	+4
Deer Park	5.83	86	. .	. . .	. . .
Fernie	10.97	109	54	100	0
Kaslo	7.13	74	56	100	0
Nelson	8.85	82	56	109	+5
Blue River	13.44	104	. .	. . .	. . .

The average water-content of the snow-cover at nine snow-courses on the watersheds of the Canadian Columbia Basin gave a forecast of 93 per cent of normal for the runoff of the Columbia River at Trail during the five-month period ending August 31, 1944. The prediction was 31 per cent greater than the actual runoff, which was the lowest since the beginning of stream-flow records in 1913. The runoff was 65 per cent of the normal for 29 years, and 11,629,000 acre-feet less than last year. At Golden the Columbia River gave a runoff 25 per cent less than that predicted, and at Revelstoke 18 per cent less than the prediction.

Table 2--Forecast and actual runoff, April to August, 1944

Main river-basin	Stream			No. snow-courses	Runoff			
	Tributary basin	Name	At		Forecast	Pct normal	Actual	Error of actual
					a-f		a-f	pct
Coastal								
Fraser	Stave	Stave	Stave Falls	3	. . . .	. . .	686,000	. . .
Powell	. . . .	Powell	Powell Lake	5	787,000	90	560,700	+45
Skagit	. . . .	Skagit	U. S. B'd'y	1	. . . .	. . .	251,700	. . .
Interior								
Columbia	Kootenay	Laxdeau	Gerrard	2	395,600	82	376,100	+ 5
Columbia	Kootenay	Duncan	Howser	1	1,192,000	69	1,305,000	- 9
Columbia	Kootenay	Elk	Elko	2	544,000	46	580,000	- 6
Columbia	Kootenay	Slocan	Crescent	1	. . . .	. . .	1,008,000	. . .
Columbia	Kootenay	Kootenay	Wardner	3	1,949,000	50	2,419,000	-19
Columbia	Kootenay	Kootenay	Glade	6	11,401,000	74[a]	. . . .	. . .
Columbia	. . . .	Columbia	Golden	3	1,775,000	85	1,424,000	+25
Columbia	. . . .	Columbia	Revelstoke	5	15,947,000	90	13,454,000	+18
Columbia	. . . .	Columbia	Trail	9	31,618,000	93	24,173,000	+31
Okanagan	Okanagan	Okanagan	Penticton	5	286,700	97	218,000	+32
Fraser	Thompson	N.Thompson	Barrier	1	6,000,000	93	5,253,000	+14

[a] Runoff-measurements discontinued in June owing to back-water from new dam.

Department of Lands,
Water Rights Branch,
Victoria, B. C.

S. H. FRAME,
Hydraulic Engineer

(Manuscript received April 14, 1945)

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(See also pp. 48, 94, 105, and 134)

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Transactions, American Geophysical Union Volume 26, Part I August, 1945

TWENTY-SIXTH ANNUAL MEETING (1945)

MINUTES, GENERAL ASSEMBLY AND SECTIONS

BUSINESS SESSION

The Business Session of the General Assembly of the American Geophysical Union was called to order by President L. H. ADAMS at 13^h18^m on Friday, June 1, 1945, in Room 101 of the Hall of Government of George Washington University, Washington, D. C., with a registered attendance of some 485 members and guests (see Appendix A for complete registration).

The minutes of the General Assembly of the Twenty-Fifth Annual Meeting on June 2, 1944, published in the Transactions of 1944 and distributed to all the membership, were approved as printed.

The annual report of the General Secretary (see Appendix B) was summarized briefly, and accepted with thanks.

Reports of Standing Committees

Membership--Chairman Johnston reported briefly for the Committee on Membership. He stated "As reported by the General Secretary, 370 new Members and Associates have been recommended by our Committee since the Twenty-Fifth Annual Meeting. The proposals for these came from 380 members of the Union; in other words, one man in six of our 2400 Members and Associates sponsored a new Member or Associate for the Union and the other five-sixths of our membership were not active in bringing in new Members or Associates. Of these 380 members who secured new proposals for the Union, 315 sponsored one or two persons; the remaining 65 who assisted the Committee on Membership secured more than half of the new Members and Associates. Thus a large part of our increase was obtained by one in 40 of our total membership. The appeal is therefore made that more individuals of our Union assist in the program for securing new Members and Associates." Some discussion followed the report and F. W. Lee suggested that the qualifications for new membership be so broadened that all persons interested in geophysics might be admitted to the Union by adding a class of Juniors; it was moved and carried that this matter be referred to the Executive Committee for consideration and such action as is deemed advisable.

Statutes and By-Laws--Chairman Harradon of the Committee on Statutes and By-Laws reported (see Appendix C) that there had been a thorough revision of the Statutes and By-Laws which would be laid before the Executive Committee for its consideration. The General Secretary reported he had discussed these revisions with Dr. Kenerson of the National Research Council and that a few minor changes had been made in accordance with Dr. Kenerson's suggestions. President ADAMS and others commented on the revised Statutes and By-Laws; there was general recognition of the fact that careful study of the revisions is required. It was moved and carried that the matter be considered in detail by the Executive Committee with authority to submit the form finally agreed upon by the Committee to the entire membership for mail ballot.

Budget--Chairman Swick of the Committee on Budget stated that the budget for the year ending June 30, 1945 was published in Part II of the Transactions of 1944 and that a suggested budget for the next year is to be submitted to the Executive Committee on June 1, 1945.

Meetings--Chairman Marble of the Committee on Meetings could not be present. The General Secretary stated that the success of the Twenty-Sixth Annual Meeting spoke for the work of that Committee.

Editorial and Publication--Chairman Fleming of the Editorial and Publication Committee stated: "The Committee is agreed that in view of the necessity for economy, the bimonthly Transactions will include reports and papers in as concise form as possible and historical summaries of previous results and comments that do not lead to definite conclusions should be brief. The amount of detail included should be governed by the importance of the results and of their interest to geophysicists. The Transactions will be arranged in departments, as follows: (1) Scientific and technical papers relating to the various aspects of geophysics; (2) Discussions of papers under (1); (3) Progress-reports in the various fields of geophysics; (4) Letters to Editor; (5) Reviews and Abstracts, Bibliography of current publications; (6) Notes (of geophysical interest) and Personalia (obituaries, changes of activity of members, errata); and (7) Union, Section, and Committee Activities. The

Union will not be responsible for statements made or conclusions drawn by contributors. All matters for (1) should have a definite scientific or technical interest and should develop aspects of the geophysical sciences. Matter for (2) may be submitted for publication within a limiting date set by the General Secretary. Items of temporary interest will ordinarily not appear in (1) but in (3 or 4).

The Committee is composed of at least one member from each Section and the member, or members, of that particular Section will have the responsibility of reviewing all communications which are received. Any comments or suggestions made by the Committee regarding the acceptance or rejection for publication in the Transactions of papers and reports will be considered by the Committee as a whole. The interest in the Committee is well evidenced by the fact that in the meetings so far held we have had excellent attendance and the meetings each extended over two to three hours."

Reports of Special Committees

National Welfare and Related Functions--Chairman Field's report for the Committee on National Welfare and Related Functions cited good progress.

Audit--Chairman McNish of the Committee on Audit reported that the Committee found the books to be in excellent condition, and complimented the office of the Executive Secretary on the clear, understandable character of all of the records. The detailed report and financial statement for the calendar year 1944 as verified by the Committee on Audit was referred to the Executive Committee for action.

Cooperation with International Commission for Study of Tidal Waves--There was no report from Chairman McKay.

Geophysical and Geological Study of Oceanic Basins--Chairman Hess, on Naval duty in the Pacific, had not prepared a report but there was comment that all of his work has close relation to the work of the Committee and with postwar release will be of great value.

Geophysical and Geological Study of Continents--Chairman Thom made a brief report on the plans of his Committee for a program of studies for several years in geophysical mapping of the United States. Mention was made of gravity work in cooperation with the Geodetic Service of Canada and the establishment of some 57 new stations using the gravity-meter loaned to the Union by the Humble Oil Company. For three years there has been study of contacts with high school students interested in earth sciences looking toward evaluation of aptitude; a brief outline of what has been accomplished is being prepared.

Time-Signal Service--Chairman Sollenberger reported briefly on time-signal service and postwar extension. In the discussion it was developed that a report on International Time-Signal Service would be useful for geophysical interests.

Cosmic-Terrestrial Relationships--Chairman Stetson summarized the report of this Committee calling attention to its war program and developments and problems of upper and lower atmosphere (see Appendix D).

Award of William Bowie Medal--Chairman Bucher stated that recommendation for the seventh annual award of the William Bowie Medal had been made and that it would be given more particular attention later in the meeting.

Precise Surveys and Maps--Chairman Swick made a summary of the Committee's work stressing great activity, difficulties attending procurement of maps from numerous map-making organizations, and limitations in distribution (see complete report in Appendix E).

Affiliation with American Geological Institute--Chairman Thom gave a brief report of this Committee (see Appendix 3 following Minutes of the Meeting of the Executive Committee of June 1, 1945).

Free Mailing--Chairman Whitten stated that the Committee had no report to make to the Union but would report certain recommendations to the Executive Committee.

A motion was made and carried that all those reports not previously accepted be accepted and placed on file.

Resolutions--Chairman Ingerson of the Committee on Resolutions recommended consideration of seven resolutions which, after discussion, were unanimously adopted as follows:

(1) RESOLUTION OF THANKS TO GEORGE WASHINGTON UNIVERSITY

WHEREAS, The 1945 meetings of the American Geophysical Union have been made possible by the kind provision of space and facilities by the George Washington University, and

WHEREAS, The meetings have been aided by the courteous cooperation of the authorities of the University, therefore be it

RESOLVED, That the American Geophysical Union extend its heartiest thanks to the George Washington University for its hospitality and request the General Secretary to express its gratitude to the President of the University.

(2) RESOLUTION ON COOPERATION BETWEEN NATIONS IN THE INTER-CONTINENTAL CONNECTION OF GEODETIC MAP-CONTROL SYSTEMS

WHEREAS, The welfare and the improvement of the standards of living of all peoples are largely contingent upon the more rapid and efficient discovery and production of useful minerals--including ores and fuels, and

WHEREAS, The needed improvements in the world's geological and geophysical methods for discovering and developing such useful mineral raw materials can be notably facilitated through the cooperative extension and inter-continental linkage of the world's several regional geodetic map-control systems, therefore be it

RESOLVED, That the American Geophysical Union express the hope that the President of the United States will consider how our nation can make practical contribution to world-peace and to the advancement of all peoples through the working out of international cooperative arrangements for the inter-connection of the Eurasian and North American geodetic map-control systems, by linkage across Bering Strait; and for similar extensions and inter-connections of geophysical and geodetic map-control systems throughout the Americas, and be it further

RESOLVED, That a copy of this resolution be duly forwarded to the National Research Council with the request that it be transmitted to the President of the United States.

(3) RESOLUTION ON MAPPING BY THE UNITED STATES COAST AND GEODETIC SURVEY AND THE UNITED STATES GEOLOGICAL SURVEY

WHEREAS, About one-half of the United States and its territories and possessions is totally unmapped and more than two-thirds of its area of three million square miles is inadequately mapped, and

WHEREAS, The needs for maps for national planning and other peace-time purposes are certain to be far greater with the passing of each year, and

WHEREAS, Mapping as a public works project, properly accomplished, will effect great savings in national economy of ultimate benefit far exceeding its cost, and

WHEREAS, There is great waste resulting from this lack of maps which inevitably accumulates, and will continue to do so with serious consequences, therefore be it

RESOLVED, By the American Geophysical Union assembled in Washington June 1, 1945, that this matter be called to the attention of the President of the United States with the urgent recommendation that the necessary appropriations be made for this work to be undertaken jointly by the United States Coast and Geodetic Survey and the United States Geological Survey working in cooperation to expedite the work within a reasonable number of years, and be it further

RESOLVED, That copies of this resolution also be forwarded by the Secretary of the American Geophysical Union to the President of the Senate, the Speaker of the House of Representatives, the Director of the Bureau of the Budget, and the Secretaries of Interior and Commerce.

(4) RESOLUTION OF APPRECIATION OF THE LATE DR. ROBERT E. HORTON

WHEREAS, The late Dr. Robert E. Horton made notable contributions to hydrology and hydrometeorology, including the measurement of snowfall and the water content of snow-cover, the relation of precipitation to aspect and slope, the maximum intensities of precipitation, long-term variations in precipitation and lake levels, the interception of snow and rain by vegetation, evaporation from the soil and bodies of water including the differences under laminar flow as contrasted to turbulent air flow, run-off erosion patterns, and infiltration --indeed the whole field of the hydrologic cycle, and

WHEREAS, He has bequeathed his exceptional library of notes and pamphlets, as well as funds, in such a way as to promote and foster research and publication in hydrology and hydrometeorology, therefore be it

RESOLVED, That the American Geophysical Union express its deep appreciation both for his researches and his farsighted provision for future investigations, and be it further

RESOLVED, That copies of this resolution be sent to Mrs. Horton and to Dr. Horton's former associates.

(5) RESOLUTION ON SUGGESTED FEDERAL MAP INFORMATION AND DISTRIBUTION OFFICE

WHEREAS, The emergency conditions existing during the past few years have made it necessary for many of the Federal surveying and map-making agencies to take part in the topographic mapping of certain important areas in the United States, and

WHEREAS, These same conditions have prevented adequate dissemination of information regarding the location of the areas surveyed and the availability of the resulting maps, and

WHEREAS, The map-using public is at present seriously handicapped by its inability to obtain all topographic maps from a single source (the United States Geological Survey) as formerly, or to obtain definite information as to what agency distributes the maps or charts needed and is therefore frequently put to unnecessary expense and annoying delay in securing these maps or charts, be it therefore

RESOLVED, That the American Geophysical Union recommend the formation, within the framework of existing Federal agencies, of a map information and distribution office responsible for furnishing accurate and complete information regarding all maps, charts, and aerial photographs published or procured by the several Federal surveying and mapping agencies; and for the actual distribution of all topographic (quadrangle) maps of the United States and its possessions now published and distributed to the public by numerous Federal agencies, and be it further

RESOLVED, That copies of this resolution be sent to the Bureau of the Budget, to the Chief Examiner, Surveying and Mapping, Bureau of the Budget; to the American Congress on Surveying and Mapping, and to all Federal surveying and map-making organizations.

(6) RESOLUTION ON POSTWAR INTERDEPARTMENTAL MAP BOARD

WHEREAS, The maps and charts of the United States and of navigable waters adjacent thereto are of the utmost importance in time of war, both to the Armed Forces and to civilian contractors, operators, and public carriers, who directly and indirectly supply the Armed Forces with munitions of war, and

WHEREAS, The severe restrictions placed on the distribution of certain types of maps and charts and the withholding of vital information necessary in constructing charts and maps have created a large amount of confusion and delay in supplying adequate charts and maps to contractors, engineers, navigators, and pilots, and have deprived the public of other useful information often resulting in duplication at heavy expense of data already existing, and

WHEREAS, Much of this confusion and delay has resulted from not having in advance an Interdepartmental Board with authority to fix security policies pertaining to the preparation and distribution of charts and maps, therefore be it

RESOLVED, That the American Geophysical Union urge that, at the conclusion of the war, an Interdepartmental Board, composed of representatives from the Army and Navy and representatives from each of the Federal surveying and mapping agencies, be established to make a thorough study of the entire subject of map and chart classification and restriction, and to prescribe definite policies to be followed during future periods of emergency, and be it further

RESOLVED, That copies of this resolution be sent to the War and Navy Departments; to the Bureau of the Budget; to the Chief Examiner, Surveying and Mapping, Bureau of the Budget; to the Chairman of the Interdepartmental Board; to Clifton A. Woodrum, Chairman, Postwar Military Policy; to the American Congress on Surveying and Mapping; and to all Federal surveying and mapping agencies.

(7) RESOLUTION ON TIME-SIGNAL SERVICES

WHEREAS, There is vital need in all astronomical, geodetic, magnetic, and seismological work for accurate time-service, and

WHEREAS, It is recognized that present war conditions have introduced complications and difficulties in maintaining routine schedules, therefore be it

RESOLVED, That the American Geophysical Union express its appreciation for all regular and special time-signal services maintained by the United States Naval Observatory, the United States Naval Communications Service, and the National Bureau of Standards, and be it further

RESOLVED, That copies of this resolution be sent to the Secretary of the Navy, the Director of the Naval Communications Service, the Superintendent of the United States Naval Observatory, and the Director of the National Bureau of Standards.

Three other Resolutions adopted by the Sections of Seismology and Meteorology were reported for the information of the Union as follows:

(8) (SEISMOLOGY) RESOLUTION ON PREPARATION OF ACCURATE TOPOGRAPHIC MAPS IN SEISMIC AREAS

WHEREAS, Seismologists are interested in strains set up in the Earth's surface because of their probable relation to earthquake causation, and

WHEREAS, Accurate topographic maps combined with repeat surveys might furnish valuable information on slow ground movements preceding earthquakes, and

WHEREAS, Such maps are necessary for the understanding of relations of local earthquakes to the topography, and

WHEREAS, Such earthquakes do occur in regions not yet mapped, therefore be it

RESOLVED, That the Section of Seismology heartily endorse all field survey projects directed toward the preparation of accurate topographic maps especially in seismic areas.

(9) (SEISMOLOGY) RESOLUTION ON TIME-SIGNAL SERVICES

WHEREAS, Satisfactory results cannot be obtained at seismograph stations in the United States and adjacent regions without the aid of radio time signals, and

WHEREAS, It is recognized that war conditions have introduced difficulties in maintaining the schedules for radio broadcast of time signals, therefore be it

RESOLVED, That the Section of Seismology of the American Geophysical Union express its appreciation for all regular and special time-signal services maintained by the United States Naval Observatory, the United States Naval Communications Service, and the National Bureau of Standards, and be it further

RESOLVED, That copies of this resolution be sent to the Secretary of the Navy, the Director of the Naval Communications Service, and the Director of the National Bureau of Standards.

(10) (METEOROLOGY) RESOLUTION ON AN IMPROVED METEOROLOGICAL BIBLIOGRAPHIC SERVICE

WHEREAS, Current meteorological bibliographies are inadequate for the needs of pure and applied climatology, and

WHEREAS, The subject and its applications are of the greatest importance to many scientific disciplines not represented in the American Geophysical Union, and

WHEREAS, An adequate biblicgraphic service can not be maintained without the cooperation of all branches of scientific disciplines, therefore be it

RESOLVED, That the Section of Meteorology request the Executive Committee to explore the possibility of creating an adequate bibliography of the past, and an adequate current bibliographic service by joint action of the American Geophysical Union and the National Research Council in cooperation with other interested groups.

Elections--The Section of Seismology reported the election of Leonard L. Murphy as Secretary from June 1, 1945, to June 30, 1947. The Section of Hydrology reported President J. E. Church, Vice-President L. G. Straub, and Secretary K. H. Beij, were to continue in their respective positions through June 30, 1947. There was no election of officers necessary for the other six Sections of the Union.

Synchronization of elections--A Special Committee of the Section of Tectonophysics submitted a report (see Appendix E) on synchronization of elections which had been adopted by the Section and which was read by Secretary Hubbert. The report was ordered referred to the Executive Committee for consideration.

New Business

Citation and Award of the William Bowie Medal--In accordance with the unanimous recommendation of the Special Committee on Award of the William Bowie Medal, F. W. Reichelderfer made the citation for the seventh award of the Medal to Professor JAKOB A. B. BJERKNES, for his service to Meteorology. Professor Bjerknes was notified by telegram of the award. President ADAMS made the presentation, in the absence of the recipient, with the request that the General Secretary forward the Medal with an appropriate letter and the unanimous congratulations of the Union. The citation and reply subsequently received follow these minutes.

Membership drive--President ADAMS commented upon the excellent work of the Committee on Membership and emphasized that all Members and Associates should take part in sponsoring additional qualified persons.

Adjournment--The Twenty-Sixth Annual Meeting was declared adjourned at 15^h11^m.

Sessions of Sections--The minutes of the meetings of the Sections of the American Geophysical Union, May 31 and June 1, 1945, are given in Appendices F to M.

J. A. FLEMING, General Secretary,
American Geophysical Union

APPENDIX A--RECORD OF 485 MEMBERS AND GUESTS WHO REGISTERED AT THE TWENTY-SIXTH ANNUAL MEETING

Abbot, C. G.
Adams, John A., Jr.
Adams, L. H.
Adams, Louise W.
Aguerrevere, Pedro I.
Aldredge, R. C.
Aldrich, Henry R.
Alexcer, V. V.
Allen, Alice S.
Ament, Richard P.
Anderson, J. B.
Anderson, Judson L.
Anderson, Nils G.
Arctowski, H.
Ashburn, Edward V.

Bailey, Martha W.
Balk, Robert
Ball, Lorraine
Balling, Eva M.
Balsam, Ella
Barton, David
Bartsch, Paul
Bateman, Alan M.
Beach, Liselotte
Beers, Norman R.
Beers, Roland F.
Beij, K. Hilding
Benedict, Wm. S.
Benfell, Vincent S.
Bennison, Allan P.
Berdan, Jean M.
Bernard, Merrill
Bernstein, Arthur
Berry, Ralph Moore
Betts, Clifford A.
Betz, Frederick, Jr.
Bodle, R. R.
Bogan, Willma W.
Borden, Frank S.
Bowie, John H.
Braaten, Norman F.
Brancato, G. N.
Breckenridge, Ida S.
Brier, Glenn W.
Bristow, G. C.
Brombacker, W. W.
Brooks, Charles F.
Brown, Annabel
Brown, Carl B.
Brown, George H.
Bryan, G. S.
Bucher, Walter H.
Buell, Miner W., Jr.
Butler, Arthur P., Jr.
Butterfield, Arthur D.

Calleway, E. B.
Cameron, Eugene N.
Capello, James J.
Capps, S. R.
Carder, Dean S.
Carlin, Albert V.
Cartwright, G. D.
Chayer, Felix
Church, Earl
Church, James E.
Church, Phil E.
Claffy, Esther W.
Clapp, Philip F.
Clark, C. O.
Cleven, Josephine
Clifford, Charles J.
Clinite, R. G.
Cloos, Ernst
Collins, W. D.
Corwin, Leonard B.
Cotton, Harold A.
Crawford, Juanita
Crone, Mary C.
Culnan, Robert N.
Curran, Eileen
Curtis, Russell E.

Daisher, B. I.
Daking, C. W. G.
Darton, N. H.
Davenport, Royal W.
Davids, Norman
Davidson, Clifford A.
Davis, Gordon L.
Davis, Robert M., Jr.
Day, Arthur L.
Dayey, Ruth
Deel, Samuel A.
Dellett, Margaret L.
Deppermann, Charles E.
Disney, L. P.
Doepke, June
Dorf, Erling
Dorsey, Herbert G.
Doty, L. Donald
Dove, W. N.
Dreyer, Robert M.
Duerksen, J. A.
Dye, Albert E.
Dye, Lucius W.

Earle, Robert A.
Edmunds, Clara S.
Eisenlohr, Wm. S. Jr.
Elliott, Robert D.
Ellison, W. D.
Emmons, Gardner
English, Arthur V.
Espenshade, Gilbert H.
Estes, Richard K.
Ewing, Lydia Frances
Eyestone, W. B.

Fairbairn, H. W.
Farnham, Frank C.
Farquhar, Frank S.
Farrell, Mary W.
Faulds, Arthur H.
Faust, George T.
Feiker, Frederick M.
Fiedler, Albert G.
Field, R. M.
Fleagle, Robert G.
Fleischer, Michael
Fleming, John A.
Flint, George M., Jr.
Flynn, Francis J.
Forbush, Scott E.
Forsland, Norma G.
Forsythe, George E.
Francis, William A., Jr.
Frank, Bernard
Frapogo, Antonio H.
Fulks, J. R.
Fuller, Richard E.

Gallagher, David
Garner, C. L.
Gartlein, Carl W.
Gaydos, Lillian
Gebhardt, Robert E.
Geiser, Murray A.
Gerson, N. C.
Gish, O. H.
Glock, Waldo S.
Goddard, E. N.
Goff, Russell H.
Gold, Harold K.
Goldstone, F.
Gonzalez, Americo
Gottschalk, L. C.
Grabski, Frank
Grad, Arthur
Grange, Jessie Cary
Graton, L. C.
Graves, G. Van A.
Green, C. K.
Green, J. W.
Greene, Dwight L.
Griggs, Allan B.
Grimaldi, F. S.
Grover, N. C.
Guild, Philip W.
Gunn, Ross
Guyton, W. F.

Hafstad, Katherine C.
Hain, E. L.
Hanavich, Charles
Hankins, Lawrence D.
Hanners, Albert J.
Harmantas, Christos
Harradon, H. D.

Harris, William D.
Harrison, Joseph O.
Harrison, L. O.
Haynes, B. C.
Heck, J. T.
Hemple, H. W.
Hendrix, William C.
Hereford, Joseph Pierce
Hershberger, John
Hertzler, Richard A.
Hess, Victor F.
Hewett, D. F.
Hickley, Thomas J.
Hobbs, Harold W.
Hodges, Louise E.
Howe, H. H.
Howland, Arthur L.
Hoyt, W. G.
Hsu, Shih-ta
Hubbert, M. King
Huff, Lyman C.
Hull, B.
Hursh, Charles R.
Hurst, Martha E.
Hurwitz, Louis
Hyde, Robert T.

Ingerson, Earl
Izzard, Carl F.

Jacob, C. E.
Jacobs, W. C.
Jacobson, Louise
Jarvis, Clarence S.
Jeffers, O. H.
Jenkins, David S.
Joerg, W. L. G.
Johnson, Ernest C.
Johnson, Hollister
Johnston, H. F.
Jones, Benjamin E.
Jones, P. R.
Juan, V.
Judson, Lewis V.

Katz, Harold W.
Keller, Fred, Jr.
Kennard, Ralph B.
Kennedy, George C.
Keopka, Frances S.
Kerr, Paul F.
Kesseli, John E.
Keulegan, G. H.
Kincer, J. B.
King, Philip B.
Kinzek, Charles B.
Kirkham, Don
Knapp, David G.
Knopf, Eleanora Bliss
Kochalove, M.
Kohler, Max A.
Kolquist, Marie H.
Korff, S. A.
Kovach, Edward M.
Kracek, Frank C.
Krieger, Medora H.
Krimgold, D. B.
Krumbein, W. C.
Kuehn, Hugo E.

Lackner, Peter R.
LaFave, Aziel
Lambert, Walter D.
Lamoureux, C. E.
Lamoureux, Wallace J.
Landen, David
Landsberg, Helmut E.
Langbein, Walter B.
Lange, Isabelle
Lanigan, Eleanor M.
Laporte, Lucile
Larsen, H. R.
Latta, Bruce F.
Laure, Linnea G.
Lay, Edwin T.
Lee, F. W.
Leet, L. Don
Leifson, G.
Lennahan, Charles M.
Lewis, James G.
Liddell, William A.
Lin, Ping-Yi
Linehan, Margaret E.
Linsley, Ray K., Jr.
Little, D. M.
Little, William S.
Longwell, Chester R.
Lorimor, Elza G.
Loughlin, G. F.
Love, S. K.
Lowdermilk, W. C.
Lusteg, Marie
Lyons, U. S.

MacDonald, T. H.
Mace, Margaret
Macelwane, James B.
Maki, Kal
Mansfield, George R.
Maris, H. B.
Markowitz, William
Marsh, Charlotte A.
Marshburn, Lena M.
Martin, Lawrence
Mason, Martin A.
Mason, Rebecca
Matthes, Francois E.
Mattice, W. A.
Mattos, Allyrio H.
McComb, H. E.
McCombs, Charles
McCormick, R. A.
McDonald, W. F.
McKay, E. C.
McKinstry, H. E.
McKnight, C. R.
McNish, A. G.
Meads, B. K.
Mears, A. H.
Medina, Guillermo
Meehan, C. Lorraine
Meier, Agnes E.
Meinzer, O. E.
Millar, John McG.
Miller, David H.
Miller, Dorothy L.
Miller, LeRoy C.
Milton, Charles
Misulia, Michael G.
Mook, C. P.
Moon, George W.
Moorehead, George J.
Morgan, H. R.
Morrison, Harriet W.
Morrison, Roger B.
Mundorff, M. J.
Munns, Edward N.
Murphy, Leonard M.
Musgrave, G. W.
Myers, Hellen Faris

Namias, Jerome
Neill, Howard W.
Neills, Richard H.
Netzer, Donald L.
Neumann, Frank
Neuschel, Virginia S.
Newlin, Delmar B.
Nicol, Allen H.
Nitch, Dorothy G.
Norton, H. W.
Nutting, P. G.

O'Keefe, D. M.

Page, B. L.
Palmer, Wayne C.
Parker, Nathan O.
Parr, A. E.
Parry, H. Dean
Parsons, Willard H.
Peoples, Joe Webb
Peterson, Barney J.
Phair, George
Pierce, Charles H.
Pike, William S., Jr.
Poling, Austin C.
Potter, Ursula Y.
Purvis, Frances

Quam, Louis O.

Ramser, C. E.
Randall, Marie
Rappleye, Howard S.
Reichelderfer, F. W.
Repetti, W. C.
Rice, Donald A.
Rigby, Malcolm
Riordan, Rosemary E.
Ritzmann, O. F.
Roberts, E. B.

Roberts, Mrs. E. B.
Roberts, Nancy
Roberts, Kenneth L.
Roberts, Ralph J.
Rogers, Judith B.
Roman, Irwin
Rooney, W. J.
Rosensohn, Janet
Ross, Clarence S.
Rowland, Everett W.
Rubey, William W.
Rudesil, O. F.
Russo, Carl
Ryzhkov, K. P.

Santos, Gabriel O.
Saver, Jonathan D.
Scharon, H. LeRoy
Schereschewsky, P. L.
Schick, Charles O.
Schlecht, W. G.
Schmidt, Thecla O.
Schmitt, Waldo L.
Schureman, Paul
Schwab, John Frederick
Scipio, L. A.
Scofield, Carl S.
Scott, Walter E.
Selby, George E.
Shands, Alexander L.
Shapley, A. H.
Sharpe, C. F. Stewart
Sharpe, Joseph A.
Shelby, Emma C.
Sheridan, L. W.
Sherman, Kenneth L.
Sherrill, Ernest
Sherry, B. J.
Shipman, Robert L.
Shmidl, Leslie E.
Shneiderov, Anatol
Shofnos, William
Showalter, A. K.
Slater, C. S.
Small, James B.
Smith, E. Dillon
Smith, H. T. U.
Smith, Janet W.
Smith, Paul A.
Smith, Waldo E.
Smith, Ward
Snyder, E. Janet
Snyder, Franklin F.
Sollins, Alfred D.
Solomon, Irving
Soucek, Edward
Spengler, Kenneth C.
Stechschulte, V. C.
Stetson, Harlan T.
Stone, Robert C.
Stow, Marcellus H.
Straley, H. W., III
Straub, L. G.
Stringfield, V. T.
Sturgeon, Doris C.
Sullivan, Mannevillette
Sumner, Howard C.
Sutcliffe, Walter W.
Suter, Max
Swainson, O. W.
Swartz, J. H.
Sweet, James S.
Swenson, Bennett
Swick, C. H.

Taylor, Arnold B.
Tewinkel, G. C.
Thayer, T. P.
Thiessen, Alfred H.
Thom, W. T., Jr.
Thone, Frank
Thornthwaite, C. W.
Thune, Howard W.
Tibbott, Edward W.
Tolman, C. I.
Torreson, O. W.
Tuttle, O. F.
Twenhofel, William S.

Zetler, Helen E.
Zies, E. G.
Zoch, Richmond T.

Vacquier, V.
Van Valkenburgs, Alvin
Van Alstine, Ralph E.
Varnes, D. J.
Vaughan, T. Wayland
Vederman, Joseph
Vestine, E. H.

Wait, G. R.
Wallis, W. F.
Waring, G. A.
Warmer, H. A.
Waters, A. C.
Watt, William G.
Weaver, John C.
Webb, James P.
Weightman, R. H.
Weiss, Leonard L.
Wells, H. W.
Wengerd, Sherman A.
Wentworth, Eleanor E.
Westerman, C. Edward
Whitten, Charles A.
Wiese, John H.
Wile, Carolyn R.
Wilgus, A. S.
Wilhelm, O. G.
Williams, Franklin G.
Williams, Gordan R.
Williams, H. M.
Williams, R. M.
Willis, John E.
Willoughby, M. Frances
Wilson, Alfred
Wilson, Ronald M.
Wilson, Walter T.
Windom, Isobel Wells
Winner, John P.
Winslow, Allen G.
Winterkorn, Hans F.
Wobus, H. B.
Work, David

Yates, Robert G.

APPENDIX B--REPORT OF GENERAL SECRETARY OF AMERICAN GEOPHYSICAL UNION TO THE GENERAL ASSEMBLY, TWENTY-SIXTH ANNUAL MEETING, JUNE 1, 1945

Membership--As of June 1, 1945, the total number of Members was 2,445, a net increase since the Twenty-Fifth Annual Meeting of 294. Twenty-nine of our Members were placed, upon request, on the Inactive List, two were reinstated, 15 resigned, and 15 were dropped because of non-payment of dues during two or more years. The deaths of 11 Members, since those indicated at the Twenty-Fifth Annual Meeting, were reported as follows:

Carl George Carlson, May 6, 1944
Robert J. Greer, May 12, 1944
Bernard Ostolenk, Nov. 26, 1944
Ozro N. Floyd, Nov. 30, 1944
George W. Pickels, Dec. 2, 1944
Thomas H. Whitcroft, Dec. 18, 1944
Thomas Riggs, Jan. 16, 1945
Luther C. Smith, Jr., Feb. 23, 1945
Albert H. Horton, March 4, 1945
Carl A. Ludy, March 13, 1945
Robert E. Horton, April 23, 1945

There are four Corresponding Members as follows: Alfonso Contreras Arias and Pedro C. Sánchez of Mexico; Owen Thomas Jones and Harold Jeffreys of England.

Executive Committee Meetings--The Executive Committee held meetings June 2, 1944, June 29, 1944, and December 12, 1944; another is to be held following the General Assembly of June 1, 1945. [Minutes of meetings of June 2 and 29, 1944, are published in Trans. Amer. Geophys. Union, Part II, pp. 334-342, 1944, and those of December 12, 1944, and of June 1 and 16, 1945, in Trans. Amer. Geophys. Union, v. 26, Part I, pp. 161-172, 1945.] The Committee continued to give special attention to relations of the American Geophysical Union with the International Union of Geodesy and Geophysics, with the International Meteorological Organization, and with geophysicists and geophysical bodies in the Western Hemisphere.

Meetings--A Joint Regional Meeting--the Union's 17th Regional Meeting--of the South Pacific Area of the Section of Hydrology was held in Los Angeles February 27, 1945.

The Twenty-Sixth Annual Meeting of the Union and its Sections was arranged for May 31 and June 1, 1945. Again the Union has the privilege of the facilities of the Hall of Government of the George Washington University through the courtesy of President Cloyd Heck Marvin. Despite war-time restrictions, the scientific program included 99 papers and progress-reports, and the registered attendance was 485. The success of this Meeting is due to the thorough preparation of the Committee on Meetings under the Chairmanship of John Putnam Marble.

William Bowie Medal--Upon recommendation of the Special Committee on the Award of the William Bowie Medal the seventh award was made to Jakob A. B. Bjerknes at the General Assembly, June 1, 1945.

Publications--The Transactions of 1944 in six Parts totaling 1066 pages (equivalent to more than 1500 pages in ordinary printers' format) were prepared for publication. Parts I to IV were distributed and Parts V and VI are complete and will be distributed by July 1945. The numbers printed were: Part I, 5200 (including 2500 for the Western Snow-Conference); Part II, 2700; Part III, 6700 (including 4000 for the American Meteorological Society); Part IV, 2700; Parts V and VI, 3000. The time required for publishing and distribution was unusually long because of war-time restrictions on paper and manpower shortage in printing and binding.

Arrangements have been completed to begin publishing the Transactions as a bimonthly journal beginning with Part I of Volume 26 in August 1945.

Representation on Divisions of the National Research Council--The Union is now represented on the Division of Foreign Relations of the National Research Council by the following members: L. H. Adams, J. E. Church, R. M. Field, J. A. Fleming, N. H. Heck, T. G. Thompson, and H. U. Sverdrup. J. A. Fleming is representative of the Union on the Division of Geology and Geography.

Finances--The report of the Committee on Audit for the calendar year 1944 is given in full on pages 166-168. During July 1944, to June 1945, the Union received $6000 from the Rockefeller Foundation; the National Research Council also continued its annual grant of $400 for the fiscal year ending June 30, 1945, and made a like grant for the year ending June 30, 1946.

Statutes and By-Laws--Extensive revisions of the Statutes and By-Laws of the Union have become necessary because of the Union's growth, and revisions were submitted at the Twenty-Sixth Annual Meeting for consideration.

International Union of Geodesy and Geophysics--Complete functions of the International Union of Geodesy and Geophysics could not be maintained because of the war. The Officers of the International Union in Great Britain and the United States, however, were able to continue some of them, thus paving the way for postwar resumption of international collaboration. It is expected a meeting in England of the Executive Committee of the International Union will be called late in 1945 or early in 1946.

The quota of $3,920.40 for adherence of the United States to the International Union of Geodesy and Geophysics for the calendar year 1944 is not yet paid. The balance of International Union funds in the United States on June 1, 1944, deposited with the Riggs National Bank, was $18,093.72.

Conclusion--The Union has added another successful year in its support of geophysical progress. Its efforts during 26 years have had much to do with the present recognition of Geophysics as a Profession.

J. A. FLEMING, General Secretary
American Geophysical Union

APPENDIX C--REPORT OF THE COMMITTEE ON STATUTES AND BY-LAWS

H. D. Harradon, Chairman
L. V. Judson M. B. Smith

At the meeting of the Executive Committee on December 12, 1944, the Committee on Statutes and By-Laws was instructed to revise the present Statutes and By-Laws for the purpose of bringing them in line with the situation of the Union. This action has been necessitated by the rapid development of the Union since its establishment in 1919. At that time the membership was limited to 65, some years later it was increased to 75, then 100, and later still all restrictions as to the number of members were removed. Since that time the membership has increased to over 2400 and its activities have extended far beyond what was envisaged in 1919. The broadening of the scope of the Union has been indicated by the addition of two new Sections, Hydrology in 1930, and Tectonophysics in 1940. This expansion is further indicated by the development of the *Transactions* from a few mimeographed minutes in the beginning to the substantial annual volumes, and now to the contemplated bimonthly journal form. It has been found necessary to provide a full-time Executive Secretary with a staff of assistants to take care of the expanded administrative work. Foreign and corresponding members have been included and local and regional meetings of the Union have been authorized, and a petition has been received for the establishment of a regional branch of the Union. Thus a thorough revision of the Statutes and By-Laws has become imperative.

The principal tentative changes made in the Statutes are as follows: The introduction of a new class of membership known as Corporation Members, thus permitting industrial organizations and institutions to join the Union paying higher annual dues than the other classes of Members enlargement of the Executive Committee of the Union; authorization of the establishment of local or regional branches of the Union with approval of the Executive Committee; and control of publications to be vested in the Editorial and Publications Committee.

The By-Laws have been largely rewritten to conform to the changes in the revised Statutes. The duties of the General Secretary and the Executive Secretary have been defined. The President has been authorized to sign checks drawn on the account of the Union in case of absence or death of the General Secretary. Details regarding the publications of the Union and their distribution have been set forth.

These revised Statutes and By-Laws have the full approval of the General Secretary, Executive Secretary, and the National Research Council. The National Research Council has given them its careful attention and suggested certain changes in the Committee's preliminary draft. We hope, therefore, in submitting these revised Statutes and By-Laws to your consideration, that it may be found possible to authorize the General Secretary to submit them to the vote of the Union.

(Note by Editor: The Statutes and By-Laws, in finally revised version approved by the Executive Committee at its meeting on June 16, 1945, by the National Research Council, and approved by the membership of the Union in the ballot that closed July 31, 1945, are printed on pages 173-177 of this issue.)

APPENDIX D--REPORT OF SPECIAL COMMITTEE ON COSMIC-TERRESTRIAL RELATIONSHIPS, 1944-45

H. T. Stetson, Chairman

C. F. Brooks
H. H. Clayton
J. H. Dellinger
J. A. Fleming
N. H. Heck
J. F. Hellweg
E. O. Hulburt
H. Landsberg
J. Q. Stewart
W. T. Thom, Jr.
N. Wiener

The activities of the Special Committee on Cosmic-Terrestrial Relationships during the past year have again been chiefly devoted to work contributing to the National war program.

Several members of your Committee have on frequent occasions been called to Washington for consultation in connection with Government projects particularly in the categories of radio communications and meteorology.

Some improvements have been made in the basis for predicting communication-frequencies, and field-strength measurements have now accumulated over a sufficient period to be profitable for analysis at the higher frequencies. It has become increasingly evident that the problem of optimum radio-propagation conditions, even at frequencies reflected from the F-layer, are dependent upon ionization-conditions integrated through the lower atmosphere in which attenuation through absorption systematically takes place. With the close of the war it is hoped that much of the results of such investigations may be promptly published to assist in a better understanding of the ionized medium and the cosmic conditions responsible for variations in propagation-conditions.

I. F. HAND reports the inauguration of simultaneous pyrheliometric measurements using vertically placed pyrheliometers facing east and south and is obtaining valuable results. A new thermoelectric pyrheliometer five times as sensitive as those in ordinary use is to be used in regular measurements of diffuse radiation.

H. H. CLAYTON has continued his investigations of solar activity and rises and falls of atmospheric pressure. Further confirmation is found for believing that increased sunspot-activity is accompanied by decreased atmospheric pressure in the equatorial region and increased pressure in high latitudes.

J. F. HELLWEG has maintained the solar program at the Naval Observatory which includes daily photographs of the Sun, the determinations of positions, areas, and counts of spots published in due course in the Monthly Weather Review. Visual spectrohelioscopic observations have been made and reported, an important item in the studies of radio-propagation conditions.

The contributions of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington to the field of cosmic-terrestrial relationships may be noted in the annual report of its Director and need not be repeated here.

A request from the Committee on National Welfare and Related Functions for suggestions relative to skills and training necessary for pursuing investigations in the fields of cosmic-terrestrial relations and for opportunities which such a field presents was answered in the preparation of a report by your Chairman after consultation with all the members of the Committee, either through personal interviews or correspondence. It is understood that such information as was forwarded is to be incorporated in a report by the Chairman of the Committee on National Welfare and Related Functions of the American Geophysical Union.

Certain members of the Committee have met from time to time for conferences in Washington and in Boston, and, in conjunction with the Chairmen of other Special Committees, in Ottawa for a consultation with the officials of the Canadian Government relative to projects requiring specifically international cooperation.

A conference with JOSEPH NEEDHAM, British representative of the Sino-British Science Cooperation Office, was held and the desirability for cooperation in an ionospheric and radio program with China was discussed. Because of the fact that the radio path between the eastern United States and the Orient passes through the region of the North Magnetic Pole it is believed that such a communication-program may prove of special interest in determining cosmic effects along the transmission-path through the auroral zone.

The Needham Laboratory has continued the coordinated program with the Interservice Radio Propagation Laboratory of the Joint Wave Propagation Committee and has extended its field-intensity program to include higher frequencies urgently needed in the further development of communications.

Reports of cosmic phenomena have been received regularly at the laboratory and have proved most valuable in connection with the work of your Committee. Certain projects other than those already mentioned are being given consideration. It is hoped these may be inaugurated at the earliest opportunity, following the cessation of the war, and that they will contribute basically to the fundamental field of geoscience.

HARLAN T. STETSON, Chairman
Special Committee on
Cosmic-Terrestrial Relationships

APPENDIX E--REPORT OF SPECIAL COMMITTEE ON PRECISE SURVEYS AND MAPS, 1944-45

C. H. Swick, Chairman

Frank S. Borden
W. H. Bucher
Carroll F. Merriam
R. B. Montgomery
J. W. Peoples
O. W. Swainson
E. H. Vestine

Precise surveying and mapping in this country have been greatly expedited during the past three or four years, because of National Defense needs. This impetus to surveying and mapping has great peace-time, as well as war-time, value, of course, and it is hoped that a large part of this increased activity may be continued after the end of the war.

The topographic quadrangle maps formerly surveyed and published chiefly by the United States Geological Survey have recently been surveyed and published by several other mapping organizations as well in order to meet the urgent needs of the War Department. The distribution of maps has, however, been severely restricted during the war. This has resulted in great inconvenience and loss to the map-using public. It has been difficult for outside individuals and organizations to find out what Federal bureau issues the quadrangle maps of any particular area and equally difficult to get the necessary permission to obtain the maps. This latter difficulty will probably be relieved soon, but it is hoped that the experience gained during the past few years will make possible better distribution of maps for essential civilian needs in any future emergency. Information regarding air photographs has also been very hard to obtain. One out-of-town member of the Committee spent several hours in Washington going from office to office trying to find out whether portions of the Rocky Mountains had been flown and photographed.

Two informal meetings of available members of the Committee were held during the year at which the above matters were the principal topics of discussion. The Committee is submitting for approval two resolutions based on these discussions, one relating to the desirability of the formation of a map-information-and-distribution office and the other recommending an Interdepartmental Board to make a thorough study of map and chart classification and restriction and to prescribe policies for future periods of emergency. These two resolutions form an integral part of this report, and are printed in the minutes of the Business Session of the General Assembly on pp. 141-143 of this issue.

In connection with the need for a Federal Map Information and Distribution Office, it is believed that somewhat similar State offices would serve a very useful purpose. These offices would be in close contact with the Federal Office and would be informed of all important changes in the availability of various types of maps relating to their States. They could also be of considerable service in collecting and distributing information about surveys, particularly about local, special-purpose surveys.

As already stated, the urgency of war mapping needs has made it necessary for many different agencies to assist in meeting these needs. As a general rule, careful planning of the work has prevented overlapping and duplication. Many improved methods have been developed but adequate time and opportunity have not always been available to analyze these methods and to describe them in sufficient detail to make them available to all other agencies. Full cooperation of map-making organizations and coordination of their efforts will be required after the war to utilize these improved methods and to prevent duplications.

In connection with the vast amount of map material which has been collected during the war, the following comments by Professor Walter H. BUCHER, quoted from a letter, are of interest: "No doubt you and other members of the Committee have already given mucn thought to the question of saving from destruction the vast mass of maps and materials which will be in the hands of the armed forces at the end of the war, and of securing adequate access to those which are filed in the various Government bureaus and similar establishments of the armed forces. This includes even quantities of map-making and map-reproducing equipment." Some steps have already been taken to make the best possible use of this material after the war.

There have been a number of important developments and more than the usual progress in surveying and mapping during the past year. Particularly in Alaska, progress has been exceptional. Last summer triangulation was completed along a very difficult section of the Coast of the Alaskan Peninsula near longitude 157°. This made it possible to extend the North American Datum of 1927 to the end of the Peninsula and on to the Aleutian Islands. The final computations for this extension of the datum will be completed in the near future and this will permit the basing of the maps and charts of this large area on a common and permanent datum.

The use of the State systems of plane coordinates for local surveys and for defining boundaries of private property has increased rapidly during the year. Eight additional States have legalized plane coordinates for surveys of private property, thus making a total of 16 States that have legally adopted these systems. Many other States will undoubtedly follow this lead within the next few years. A new publication has recently been issued by the United States Coast and Geodetic Survey entitled "The State plane coordinate systems." It is designed primarily as a manual for surveyors.

Plans for postwar projects include several large river-developments somewhat similar to that of the Tennessee River. Large-scale surveys are in progress on at least two of these projects--the Columbia and the Missouri rivers--and it is understood that the mapping will follow closely.

In the report of the Committee a year ago mention was made of a list of definitions of geodetic terms which had recently been completed at the Coast and Geodetic Survey. Pressure of urgent war work has delayed the photoprinting but it is now under way.

Mapping of all kinds has been stimulated very greatly by the war. Rapid methods of photogrammetry, forced to their maximum capacities by the urgent needs of the Allied Armies and their Air Forces, have advanced geographic knowledge to an extent almost beyond the reach of imagination. But the advancements in skill, experience, and method, the great accumulations of improved equipment, aerial photographs, and trained personnel, all constitute a momentum gained in the mapping effort that is potentially even more valuable to the future than the maps already produced for the war. That momentum must be maintained without interruption while it is being redirected toward peacetime mapping.

One of the outstanding developments in mapping in recent years is the reconnaissance mapping-program of the Army through which nearly 10,000,000 square miles have been photographed by the Army Air Forces and maps compiled by techniques and methods developed by the United States Geological Survey. As part of this program, 80 per cent of Alaska has been covered by such compilation. The Canadian Government has officially adopted this method for reconnaissance mapping. Australia and many other countries are now considering the same program. In connection with this reconnaissance mapping the use of the prismatic astrolabe by the Army Air Forces has resulted in more than 1,000 astronomical determinations of position. Revolutionary new techniques in process of development will probably replace some of the conventional methods now used in establishing the lower grades of control for this type of mapping.

The application of multiplex projectors to speed the domestic mapping that seemed so important in the beginning of the war for purposes of defense will long be remembered as an outstanding activity. Subsequently the multiplex has been devoted to the very important compilation of battle maps of combat areas.

The Office of the United States Geological Survey, in Clarendon (Arlington, Virginia), has maintained a production capacity of about 3,000 square miles a month. At the present time, almost all the mapping is of foreign areas but it is expected to turn to domestic mapping as soon as war conditions will permit. Of possible interest to geologists are the experiments which have been made of compiling with multiplex projectors geologic maps from airplane pictures on which geologic boundaries have been plotted.

New techniques have been perfected for rapid production of shaded relief-maps and relief-models by both Government agencies and private contractors. Undoubtedly maps of these types will be more widely available after the war.

All geophysicists are aware of the tremendous part played by surveys and maps during the present war. New techniques for producing maps within a few days that would have required an equal number of weeks or months a few years ago have been developed. Great numbers of our fighting men have learned by hard experience the difference between a poor map and an accurate one. When these men return home they will undoubtedly be interested in any possible improvement in the mapping situation in this country. Every effort should be made by the American Geophysical Union and other vitally interested organizations to promote the completion of an adequate and accurate topographic map of this country.

APPENDIX F--REPORT OF THE COMMITTEE ON SYNCHRONIZATION OF ELECTIONS OF THE SECTION OF TECTONOPHYSICS

Earl Ingerson, Chairman
W. W. Rubey Aaron Waters

The Committee on Synchronization of Elections has discussed the matter of simultaneous election of officers for the Union and all of its Sections.

Other groups that have a somewhat similar organization arrange their elections so that there will not be a complete turnover at any one time, for example, the National Research Council. Even in organizations in which it is customary for officers to be elected each year there is usually a Council or Board of Directors who are elected for two or more years and whose terms are staggered so that not more than one-third of the members go out of office at one time. In addition, it is common for one or more retiring officers to be on the Council for the following year.

It is the consensus of the Committee that some such arrangement makes for continuity of effort and efficiency of administration, and that the American Geophysical Union should not abandon its present system without more consideration than appears to have been given to the matter. Perhaps it would be well to stagger the elections in Sections more systematically than has been done in the past.

It is the unanimous recommendation of the Committee, therefore, that the present election schedule for the Section of Tectonophysics be maintained and that the Section go on record as opposing synchronization of all elections.

APPENDIX G--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

The annual meeting was called to order by the President, W. D. Sutcliffe, at $09^h\ 05^m$, June 1, 1945, in Room 202, Hall of Government, George Washington University, Washington, D. C (for attendance, see Appendix A).

The minutes of the previous meeting have been published and no corrections or additions have been received. The President declared them approved as published.

J. B. Small, representative of the Section of Geodesy on the Committee on Membership, reported that 75 of the new Members of the Union affiliated with the Section of Geodesy. Out of the total membership of 2445 in the American Geophysical Union, 450 are affiliated with the Section of Geodesy. Mr. Small urged each Member to contact the professors in the geophysical fields in his Alma Mater and invite them to membership in the Union.

C. A. Whitten reported on the nature of the bimonthly Transactions. He pointed out that each issue would contain some scientific papers, not necessarily limited to those read at the Annual Meeting. Discussions on the papers are to be invited. Other features of the Transactions will be news items and book reviews.

C. H. Swick, Chairman of the Special Committee on Precise Surveys and Maps, reported that two problems had been given special consideration by the Committee on Precise Surveys and Maps; one was the need for a map-information office, the other was the desirability of relieving restrictions on distribution of maps. The publication on definition of geodetic terms has been delayed but will soon be printed. Eight States have legalized plane coordinates during the year, bringing the total to 16 States.

W. D. Lambert, Chairman of the Committee to Consider the Establishment of an International Journal of Geodesy, moved to discharge the Committee as there was no immediate need for such a publication, since the new bimonthly Transactions of the American Geophysical Union and the revival of the Bulletin Géodésique will take care of the present needs. The motion was passed.

Lambert reported some news he had received from the following foreign members of the International Association of Geodesy: W. Heiskanen; F. A. Vening Meinesz; G. Perrier; and H. Seligmann.

C. J. Clifford, Chairman of the Section's Committee on Resolutions (B. L. Page and Paul Campbell are the other members), proposed three resolutions on maps and mapping, which were adopted at the assembly of the Union [see Resolutions (3), (5), and (6), pp. 141-142].

The business meeting was adjourned, and the following scientific papers were presented:

(1) R. M. FIELD: F. A. Vening Meinesz--A Geodesist's contribution to Geoscience
(2) C. F. FUECHSEL: Vertical-control surveys for reconnaissance mapping
(3) A. C. POLING: Triangulation-datums in Alaska
Discussed by C. H. SWICK and W. MARKOWITZ
(4) EARL CHURCH: Special problems in aerial photogrammetry
Discussed by O. S. READING
(5) WILLIAM MARKOWITZ: Redeterminations of longitude and latitude
Discussed by C. H. SWICK
(6) JOHN E. WILLIS: Some developments of constant-altitude instruments for determining longitude, latitude, and star-positions
(7) H. R. LARSEN: Gurley four-inch Army theodolite
(8) H. W. HEMPLE: Recent progress in geodetic surveys of the United States Coast and Geodetic Survey
(9) MANUEL MEDINA: Trabajos geodésicos en México en el perfodo junio 1944-abril 1945 (by title)
(10) GEORGE WOOLLARD: Gravity-observations in the Maritime Provinces (by title)

The meeting adjourned at $13^h\ 00^m$.

J. A. DUERKSEN, Secretary

APPENDIX H--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF SEISMOLOGY, AMERICAN GEOPHYSICAL UNION

The Annual Meeting of the Section of Seismology was called to order by the President, V. C. Stechschulte, at $09^h\ 15^m$, June 1, 1945, in the Hall of Government, George Washington University, Washington, D. C. (for attendance see Appendix A).

The reading of the minutes of the last meeting was dispensed with as they had already been published in the Transactions of 1944. As no corrections have been received, they were declared approved as printed.

Committee on Nominations [H. Landsberg (Chairman), D. S. Carder, F. Sohon] nominated L. M. Murphy for Secretary for a two-year period beginning July 1, 1945. No other nomination was made and the candidate was duly elected.

The Section's Committee on Resolutions [R. R. Bodle (Chairman), J. B. Macelwane] presented two resolutions, on Accurate Time-Service and on Topographic Mapping. They were unanimously adopted and referred to the Committee on Resolutions of the Union [see Resolutions (7) and (8), p. 142].

H. Landsberg, an advisor to the Twentieth Air Force, requested an unbiased opinion of some authoritative body, such as the Section of Seismology of the American Geophysical Union and some prominent seismologists, in regard to the possibility of B-29 bombers setting off great earthquakes or eruptions in Japan and nearby islands by dropping bombs in the craters of volcanos. The Section of Seismology went on record as saying that it would be utterly fantastic to expect that such bombings could serve as trigger forces to cause such earthquakes or eruptions.

J. B. Macelwane stated that J. Coulomb, Editor of the Annales de Géophysique, a geophysical magazine, would be pleased to receive papers written in English from American geophysicists.

There being no further business, the Section proceeded to the scientific papers as follows:

(1) FRANK NEUMANN: Progress-report on seismological activities of the United States Coast and Geodetic Survey
(2) L. DON LEET: A portable three-component seismograph for vibration-problems
(3) D. S. CARDER: Influence of reservoir-loading on earthquake-activity in Boulder Dam Area
(4) V. CONRAD: On earthquakes, atmospheric pressure, and geological structure
(5) FLORENCE ROBERTSON: On long-period seismographic disturbances
(6) B. GUTENBERG and C. F. RICHTER: Earthquake-study in Southern California, 1944
(7) ANATOL J. SHNEIDEROV: Microseisms as a result of magneto- and electro-striction in some ferrous and polarized rock-deposits
(8) J. R. GOBERNA and L. S. BUCKIE: The earthquake at Belleville, Illinois, June 14, 1944
(9) LEONARD M. MURPHY: Winter microseisms

The meeting adjourned at $12^h\ 00^m$.

L. M. MURPHY, Acting Secretary

APPENDIX I--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF METEOROLOGY, AMERICAN GEOPHYSICAL UNION

The Twenty-Sixth Annual Meeting of the Section of Meteorology was held May 31, 1945, in two sessions from $09^h\ 15^m$ to $12^h\ 00^m$ and from $14^h\ 15^m$ to $17^h\ 00^m$, in Room 101, Hall of Government, George Washington University. About 150 Members and guests were present (for attendance see Appendix A).

President Reichelderfer presided at the morning session. In his opening remarks he called attention to the remarkable increase in the membership of the Section during the past year, mentioning that there had been 136 new affiliations with the Section. These, added to the previous 748, made a total of 884 Members of the Union affiliated with the Section at the time of the meeting. He remarked that in spite of restrictions on travel, several Members from out of town were present and that even a few guests from abroad were attending the meetings. He drew attention to the Committee on Resolutions [R. T. Zoch (Chairman) and L. P. Harrison] and stated that any resolutions must be in their hands before the close of the session so that they could be prepared for submission to the Section in the afternoon.

The reading of the minutes of the previous meeting was dispensed with as they had already been printed in the Transactions of 1944, and no corrections or additions had been received.

C. F. Brooks then spoke of the important contributions to hydrology and meteorology of the late Dr. ROBERT E. HORTON and read extracts from his will pertaining to a bequest to the American Geophysical Union. He proposed a resolution of appreciation which was later adopted by the Section for submission to the General Meeting. A resolution of thanks to the George Washington University for the use of the buildings was passed. [These Resolutions, as adopted by the General Meeting of the Union, are published in the minutes of that meeting, p. 141-143].

Reports of the Research Committee on Climatology and of the Research Committee on Extended Forecasts were presented by their respective Chairmen, A. E. Parr and J. Namias. At the suggestion of the former a resolution recommending the establishment and maintenance of a bibliography of climatological literature was adopted [see p. 143].

In addition to the reports of Committees mentioned above, the scientific program consisted of 14 papers as follows:

(1) E. V. ASHBURN and L. L. WEISS: The variation of vorocity in the atmosphere
(2) V. CONRAD: Some physical remarks upon the destructive effects of the hurricane (presented by R. H. WEIGHTMAN)
(3) C. E. DEPPERMAN: Some aspects of the typhoon-problem
(4) F. E. MATTHES: The glacial anticyclone theory, examined in the light of recent meteorological data from Greenland (by title)
(5) C. E. LAMOUREUX: Duration-frequencies of low ceilings on the United States Pacific Coast
(6) C. G. ABBOT: Correlations of solar variation with Washington weather
(7) P. E. CHURCH: Steam-fog on Lake Michigan
(8) S. S. VISHER: Average and extreme range in degree-day units in the United States (presented by J. B. KINCER)
(9) R. G. FLEAGLE: The field of vertical motion in selected weather-situations
(10) C. W. THORNTHWAITE: The moisture-factor in the atmosphere
(11) P. F. CLAPP: Stability of the Westerlies
(12) L. W. SHERIDAN: A study of Northern Hemisphere pressure-center tracks
(13) V. CONRAD: Daily course of precipitation on coast versus interior in relation to forecasting (by title)
(14) N. R. BEERS: Divergence of the horizontal wind

Because of the restrictions of travel imposed by the Office of Defense Transportation, arrangements had been made for papers of authors living at a distance who could not attend the meeting, to be presented by others. It is proposed to print the reports and papers in the bimonthly issues of the Transactions in the approximate order of their receipt.

H. D. HARRADON, Secretary

APPENDIX J--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY, AMERICAN GEOPHYSICAL UNION

The Twenty-Sixth Annual Meeting of the Section of Terrestrial Magnetism and Electricity was held in the Hall of Government, The George Washington University, on May 31, 1945. The session was called to order at $09^h 15^m$ in Room 203 with President H. F. Johnston occupying the chair. There were 73 Members and guests in attendance. The President welcomed the group and reminded all present of the importance of filling out a registration card at the desk in the lobby (see Appendix A for registered attendance).

The minutes of the Twenty-Fifth Annual Meeting were approved as published, after it was ascertained that there were no corrections to be made. The President called for any announcements that were in order, and the Secretary read the title of a paper that had been received from Alfonso de la O. Carreno (see below, item 2) too late to incorporate in the printed program. The President pointed out that this paper was in addition to the one which the same author had submitted last year [Trans. Amer. Geophys. Union, Part IV, pp. 575-84, 1944].

The President stated that any papers received during the year would be passed upon by the Editorial and Publication Committee of the Union for publication in the Transactions. He then called for a report of the Committee on Units. H. H. Howe responded with a brief report, to the effect that in accordance with the prevailing opinion of the members of the Committee, no resolution was to be submitted for action at this meeting. However, he agreed to submit a more extended report for publication in the Transactions after the President pointed out that much work had been done by the Committee and that circulation of such a report would tend to facilitate consideration at future meetings of the matters involved.

The Committee on Resolutions was next called upon. W. J. Rooney presented two resolutions for consideration, pertaining to Government map activities [see Minutes of Business Session of the Union, Resolutions (5) and (6) for text as finally adopted, pp. 141-143]. A motion to approve these Resolutions for transmission to the Committee on Resolutions of the Union was made, seconded, and carried.

The President then mentioned that as Chairman of the Committee on Membership of the Union he had some interesting statistics on the increase in membership; that of 370 new members, 76 had requested affiliation with this Section, bringing the total affiliations of the Section to 403 at the present time, in a total Union membership of 2,445.

There was some discussion of a tentative proposal by H. H. Howe for a resolution urging on various Governments restoration of magnetic observatories which had been destroyed by military action. O. W. Swainson suggested that in some cases such action would be either unneeded or futile at this time. The President remarked that it would be a fine thing if the United States Coast and Geodetic Survey could supply the instruments, supplies, etc., for carrying out restorations. He also referred briefly to the situation in the U. S. S. R., as reported by N. V. Pushkov in a letter of which an account will be published in the Journal of Terrestrial Magnetism and Atmospheric Electricity [see v. 50, pp. 148-149 of that Journal], stating that three observatories had been destroyed, and particularly that whereas the Russians had left all equipment intact on their retreat in 1942 (in one case the Germans continued the variation-work with only one day's loss of record), on the other hand the same buildings and instruments were systematically charged with time-bombs by the retreating Germans as the Russians approached the observatories in 1944. Destruction was complete, except for one variation-building where the time-bomb failed to explode. However, it is planned to restore and expand the Russian program of magnetic observatory work, enlarging it to include related fields.

As there was no further business, the scientific program proceeded at $09^h\ 32^m$ with the following papers and discussions thereof:

(1) H. W. WELLS: Sporadic-E ionization at Watheroo Magnetic Observatory
(2) ALFONSO DE LA O. CARREÑO: The two non-parallel layers problem according to the new development of the potential-drop-ratio method of electrical prospecting (by title)
(3) J. H. NELSON and JOEL B. CAMPBELL: Additional data on the spontaneous increase of a magnetic moment (presented by H. H. HOWE)
(4) W. J. ROONEY: Diurnal-variation anomalies at Tucson
(5) A. G. McNISH and R. E. GEBHARDT: An induction-magnetometer
(6) H. B. MARIS: Phase-shifts in the 27-day magnetic cycle (by title)
(7) O. W. SWAINSON: Magnetic work of the United States Coast and Geodetic Survey from April 1944 through March 1945 (by title)
(8) V. F. HESS and EVA BALLING: A new determination of Eve's constant for the free atmosphere
(9) EDWARD M. KOVACH: The meteorological influences upon the radon-content of the soil-gas
(10) C. W. GARTLEIN: Progress-report on the National Geographic Society-Cornell University study of aurora
(11) ANATOL J. SHNEIDEROV: Braking effect of electrostatic forces in the theory of pulsating Earth (by title)
(12) J. A. FLEMING: Researches in terrestrial magnetism and electricity at Department of Terrestrial Magnetism, Carnegie Institution of Washington, from April 1944 through March 1945 (by title)

The meeting was adjourned at $12^h\ 55^m$.

DAVID G. KNAPP, Secretary

APPENDIX K--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF OCEANOGRAPHY, AMERICAN GEOPHYSICAL UNION

The Annual Meeting of the Section of Oceanography was held in Room 202, Hall of Government, George Washington University, May 31, 1945. In the absence of President Sverdrup, the meeting was called to order by Vice-President Schmitt at $14^h\ 08^m$ (for registered attendance, see Appendix A).

The minutes of the previous meeting were approved as published in the Transactions of 1944 [Part II, p. 382].

The meeting then proceeded to the scientific papers, one of which was read by title. Because of military duties, Major H. R. Seiwell was unable to submit his paper.

(1) G. S. BRYAN: The oceanographic work of the United States Hydrographic Office during the past year
(2) R. R. WAESCHE: Oceanographic interests and activities of the Coast Guard
(3) L. O. COLBERT: Oceanographic activities of the Coast and Geodetic Survey during the past year
(4) H. U. SVERDRUP: Research within physical oceanography and submarine geology at the Scripps Institution of Oceanography during April 1944 to April 1945 (by title)
(5) H. R. SEIWELL: Further general remarks on problems of practical military oceanography (by title)
(6) WALDO E. SMITH: Some observations on water-levels and other phenomena along the Bosporus

The meeting adjourned at 15^h 20^m.

L. P. DISNEY, Secretary

APPENDIX L--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF VOLCANOLOGY, AMERICAN GEOPHYSICAL UNION

The Annual Meeting of the Section of Volcanology was called to order by President R. E. Fuller May 31, 1945, at 14^h 05^m in Room 203, Hall of Government, George Washington University, Washington, D. C. (for registered attendance, see Appendix A).

There was no business to transact, and no reports from Committees.

The President called attention to the Business Meeting of the Union on June 1, 1945, and urged a good attendance.

Eight scientific papers were then presented as follows:

(1) H. R. GAULT: Explosion-breccia, Wrangell District, southeastern Alaska (presented by W. S. TWENHOFEL and discussed by R. E. FULLER)
(2) F. C. KRACEK: Phase-relations of silver sulfide with silver and sulfur
(3) T. P. THAYER: Preliminary chemical correlation between chromites and the containing rocks
(4) R. E. FULLER: A report on the United States Committee for the Study of the Parícutin Volcano
(5) L. C. GRATON: Genetic significance of Parícutin (by title)
(6) HOWEL WILLIAMS: Geologic setting of Parícutin (presented by R. E. FULLER)
(7) ERLING DORF: Observations on the preservation of plants in the Parícutin Area (in addition to his own Kodachromes, Dorf showed some taken by W. F. FOSHAG of the buried cathedral at San Juan)
(8) E. M. ZIES: Temperatures at Parícutin

All except papers (4), (5), and (6) were accompanied by lantern-slides, many of which were in color.

The most popular attraction of the session was two reels of color movies of Parícutin shown by O. O. FISHER; the first reel, taken by F. H. POUGH of the American Museum of Natural History, was presented after the third paper, and the other at the close of the session. The principal features shown were a spectacular night eruption of the "Hornitos," details of motion of the lava-flows, and destruction of the town of San Juan. E. M. ZIES in discussion of FISHER'S movies suggested that a physicist and geologist collaborate in a study of the physical aspects of movement of the lava together with temperature-relations.

The meeting adjourned at 17^h 10^m.

T. P. THAYER, Acting Secretary

APPENDIX M--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF HYDROLOGY, AMERICAN GEOPHYSICAL UNION

All sessions were held in Room 102 of the Hall of Government of The George Washington University, Washington, D. C. on May 31 and June 1, 1945 (see Appendix A for registered attendance).

The Business Meeting was called to order by President Church at 09^h 10^m, May 31, 1945. President Church reviewed briefly the work of the Section for the past three years. The Secretary announced the following actions of the Executive Committee:

(a) In accordance with permissive action by the Executive Committee of the Union to bring all elections into synchronization, no elections would be held in the Section until 1947.

(b) Two suitable awards will be made at each Annual Meeting, beginning in the year 1946: (1) To the author whose first published hydrologic paper is judged best in the field of Hydrology, published in the Transactions of the Union during the calendar year preceding the award (the author must have received his bachelor's degree less than ten years previous to the date of publication); (2) to the author of the best paper in the field of Hydrology, published in the Transactions of the Union during the calendar year preceding the award.

Attention was called to the minutes of the meeting in 1943 [Amer. Geophys. Union, Trans. of 1943, Pt. II, pp. 767-778] containing in particular a report of the Sub-Committee on Research Committees with detailed statements of the purposes of these Committees, a report of the Sub-Committee on Prizes and Awards, and a report of the Sub-Committee on Regional Meetings. These give a complete review of past activities and recommendations for organization and policy.

Waldo E. Smith presented reports on the activities of the Committee on Membership and the Committee on National Welfare and Related Functions of the Union.

The President appointed L. G. Straub, Waldo E. Smith, and K. H. Beij as members of a Committee on Resolutions to serve until the Annual Meeting of 1947, with power to add other members to the Committee.

The Business Meeting adjourned at 09^h 45^m and immediately the first scientific session was begun. The President introduced Vice-President Straub who took the chair for this session, at which the following reports and papers were presented:

(R1) MERRILL BERNARD: Report of the Research Committee on Precipitation
(R2) J. E. CHURCH: Report of the Research Committee on Snow
  (1) R. W. GERDEL: The dynamics of liquid water in deep snow-packs (by title)
(R3) F. E. MATTHES: Report of the Research Committee on Glaciers
(R4) H. G. WILM: Report on the Research Committee on Evaporation and Transpiration (presented by C. W. THORNTHWAITE)
  (2) N. W. CUMMINGS: The reliability and usefulness of the energy-equations for evaporation (by title)
    Discussion by BENJAMIN HOLZMAN (by title)
  (3) A. R. CROFT: Water-loss from stream-surface and riparian vegetation (by title)
(R5) G. W. MUSGRAVE: Report of the Research Committee on Infiltration
  (4) R. E. HORTON: Infiltration and runoff from forested areas suring the snow-melting season (presented by G. W. Musgrave)
    Discussion by K. L. ROBERTS
  (5) W. D. ELLISON: Some effects of raindrops and surface-flow on soil-erosion and infiltration (illustrated with motion pictures)

The session adjourned at 12^h 55^m.

The session on the afternoon of May 31, 1945, was called to order at 14^h 10^m by President Church and the following reports and papers were presented:

(R6) F. J. VEIHMEYER: Report of the Research Committee on Physics of Soil-Moisture (by title)
  (6) L. L. HARROLD and F. R. DREIBELBIS: An accounting of the daily accretion, depletion, and storage of soil-water as determined by weighing monolith lysimeters (by title)
    Discussion by B. T. SHAW and C. W. THORNTHWAITE (by title)
  (7) A. A. KALINSKE: Application of statistical theory to velocity and suspended-sediment measurements in rivers (by title)

(R8) S. T. HARDING: Report of the Research Committee on Lakes (by title)
(R9) C. S. HOWARD: Report of the Research Committee on Chemistry of Natural Waters (presented by S. K. LOVE)
(R10) W. C. LOWDERMILK: Report of the Research Committee on Erosion
(8) P. E. CHURCH: Lake Michigan's annual temperature-cycle
(9) MAURICE DONNELLY: Four families of curves in soil-erosion and runoff (by title)

The session adjourned at 15^h 45^m.

The session on the morning of June 1, 1945, was called to order at 09^h 10^m by President Church. He introduced R. A. Hertzler, Chairman of the Committee on Program of the Section, who took the chair.

The Committee on Resolutions presented a resolution relating to Robert E. Horton, which was unanimously approved and forwarded to the Union's Committee on Resolutions. [For Resolution as adopted by the Union see p. 141.]

Reports and papers were then presented as follows:

(R7) L. G. STRAUB: Report of the Research Committee on Dynamics of Streams
(R11) S. W. LOHMAN: Report of the Research Committee on Ground-Water
Discussion by C. E. JACOB
(10) C. E. JACOB: Radial flow in a leaky artesian aquifer
Discussion by DON KIRKHAM
(11) DON KIRKHAM: Artificial drainage of land: Stream-line experiments--the artesian basin (III)
Discussion by C. E. JACOB
(12) C. E. JACOB and H. H. COOPER, Jr.: Generalized graphical method evaluates formation constants and summarizes well-field history
(R12) R. W. DAVENPORT: Report of the Research Committee on Runoff
(13) E. W. LANE and KAI LEI: An index of stream-flow variability (by title)
(14) C. S. JARVIS: Rainfall- and runoff-relations
Discussion by C. F. IZZARD
(15) B. F. KIMBALL: Assignment of frequencies to an ordered series of statistical data (by title)
(16) H. N. HOLTAN: Time-condensation in hydrograph-analysis (by title)
Discussion by L. K. SHERMAN (by title)
(17) C. J. COOPERRIDER, H. CASSIDY, and C. NIEDERHOF: Forecasting stream-flow in the Southwest, Salt River, Arizona (by title)
(18) H. W. HOBBS: Behavior of small agricultural watersheds under various land-use practices
Discussion by W. B. LANGBEIN
(19) E. J. GUMBEL: Simplified plotting of statistical observations (by title)

The session adjourned at 12^h 28^m.

The session on the afternoon of June 1, 1945, was called to order at 15^h 00^m by President Church. He introduced C. W. Thornthwaite who took the chair. The meeting was a round-table discussion on the theme "The delineation of Hydrologic Regions in the United States." Those who participated in the lively discussion of the subject were: Merrill Bernard (regarding precipitation); R. W. Davenport (regarding runoff); G. W. Musgrave (regarding infiltration); F. E. Matthes (regarding glaciers, snow, and physiography); C. W. Thornthwaite (regarding patterns of distribution); O. E. Meinzer (regarding ground-water); Charles F. Brooks; D. B. Krimgold; K. L. Roberts; R. A. Hertzler; Charles R. Hursh; C. E. Jacob; and others. The meeting adjourned at 17^h 00^m.

K. HILDING BEIJ, Secretary

APPENDIX N--MINUTES OF THE ANNUAL MEETING OF 1945, SECTION OF TECTONOPHYSICS, AMERICAN GEOPHYSICAL UNION

The Annual Meeting of the Section of Tectonophysics of the American Geophysical Union was held on the morning of May 31, 1945, in Room 202 of the Hall of Government, George Washington University, Washington, D. C. (see Appendix A for registered attendance).

The meeting was called to order by President Ernst Cloos at about $09^h 10^m$. The minutes of the previous Annual Meeting were approved as published.

The problem of synchronization of the elections of the various Sections was next considered. A suggestion had previously been made by the General Secretary that it would be desirable to have the election of officers of the various Sections of the Union synchronized, so that all elections would occur at the same times, at three-year intervals, beginning in 1947. One reason given for this was that it would require less frequent revision of the official stationery of the Union. In response to the suggestion of the General Secretary, the President had appointed a Committee, consisting of Earl Ingerson (Chairman), W. W. Rubey, and Aaron Waters, to consider the problem of synchronization of the elections in so far as it involved the Section of Tectonophysics. The Committee report, as given in Appendix E, was adopted, following ample discussion, as the policy of the Section of Tectonophysics.

The President called attention to the fact that while no Section Committee on Resolutions had been appointed, an important Resolution pertaining to the early completion of the topographic map of the United States had originated within the Section and had been referred to Earl Ingerson as Acting Chairman of the general Committee on Resolutions of the Union [see p. 141].

There then followed the scientific session, at which the following papers were presented:

(1) O. G. WILHELM: Observation on growth and structure of Gulf Coast salt-domes
(2) E. B. KNOPF: Postwar study of experimentally deformed rocks
(3) ROBERT BALK: Shelburne Falls Gneiss-dome, Massachusetts
(4) CHESTER R. LONGWELL: Low-angle normal faults in the Basin and Range Province
(5) O. F. TUTTLE: Structural relations of liquid inclusions in the crystalline rocks of the Washington (D. C.) Area
(6) EARL INGERSON and O. F. TUTTLE: Relations of lamellae and crystallography of and fabric directions in some deformed rocks
(7) ANATOL J. SHNEIDEROV: Isostatic compensation in the ruptures of the continental shelves

The paper by Wilhelm was discussed by Longwell, Thom, and the President; that of Mrs. Knopf by the President and Hubbert. Balk's paper was discussed by Longwell and an unidentified person. The paper presented by Longwell was discussed by Thayer, McKinstry, and Hubbert. Tuttle's paper was discussed by Kerr and King, and that of Ingerson by Mrs. Knopf. The concluding paper by Shneiderov was discussed by Longwell and Wilhelm. The meeting was adjourned at $13^h 00^m$.

M. KING HUBBERT, Secretary

SUPPLEMENTARY SUB-REPORT TO APPENDIX D ON COSMIC-TERRESTRIAL RELATIONSHIPS [see pp. 149-150]

CHARLES F. BROOKS reports as follows on work at the Blue Hill Observatory (copy received July 20, 1945):

An as yet incomplete attempt has been made by BERNHARD HAURWITZ to compute the possible effect on atmospheric pressure of variations in temperature of the ionosphere and ozonosphere owing to the large changes in the ultra-violet received from the Sun. The aim is to find the magnitude of pressure-changes on the Earth's surface that may be expected directly as a result of solar variability, this computation to be compared with the variations of observed pressure that have been plausibly ascribed by H. H. CLAYTON to solar variations.

A large factor in the depletion of solar radiation during its passage through the atmosphere being scattering by the atmosphere, it is of interest to know how much this scattering is. The diffuse short-wave radiation from the sky is a good index of scattering. W. GORCZYNZKI has prepared manuscripts on diffuse radiation the world over and on diffuse radiation at Blue Hill. The latter is a clever application of ratios of diffuse to direct radiation under different conditions of cloudiness and solar altitude as observed at Nice and Gdynia to the total radiation on a horizontal surface at Blue Hill, thereby obtaining the presumptive diffuse radiation. A check of this is in progress at Blue Hill by Miss S. H. WOLLASTON under the direction of C. F. BROOKS and I. F. HAND, by computing from the intensity of the solar beam at normal incidence the intensity on a horizontal surface, and then subtracting this from the total radiation measured on a horizontal surface.

The Blue Hill automatic record of total radiation on a horizontal surface and of radiation at normal incidence directly from the Sun, with occasional division of the rays by yellow and red filters, has been practically continuous since the fall of 1932--nearly 13 years.

MINUTES OF EXECUTIVE COMMITTEE MEETINGS, AMERICAN GEOPHYSICAL UNION

Minutes of June 1, 1945

The meeting was called to order at $15^h 25^m$, June 1, 1945, by President Adams in Room 202 of the Hall of Government, George Washington University, Washington, D. C.

Present--Twenty-nine persons were present, namely: L. H. Adams, W. H. Bucher, J. E. Church, E. Cloos, L. P. Disney, J. A. Duerksen, R. M. Field, J. A. Fleming, H. D. Harradon, M. K. Hubbert, E. Ingerson, H. F. Johnston, D. G. Knapp, W. D. Lambert, W. C. Lowdermilk, A. G. McNish, F. W. Reichelderfer, I. Roman, W. W. Rubey, W. L. Schmitt, Waldo E. Smith, M. P. Sollenberger, V. C. Stechschulte, H. T. Stetson, W. D. Sutcliffe, C. H. Swick, T. P. Thayer, W. T. Thom, Jr., and C. A. Whitten. R. E. Fuller, who designated T. P. Thayer as his alternate, N. H. Heck, and H. U. Sverdrup were excused because of absence from the city or previous engagements.

Approval of Minutes--Minutes of the meeting of December 12, 1944, were distributed by mail. Two corrections have been indicated, namely: (1) Page 3 in the paragraph under International Union of Geodesy and Geophysics, the reference made in Nature should be November 18, 1944, instead of November 8, 1944; and (2) page 9 in the paragraph under American Geological Institute, Dr. Cloos advised that the statement "16 persons were in attendance at the meeting, all observers without the power to do anything" is incorrect, and that on December 27 he received a letter from Mr. Thiesmeyer stating that only the representatives of the American Geophysical Union and the Geological Society of America were observers and the others were official representatives sent to negotiate and consider, but not to commit. The minutes as circulated and with these corrections were approved.

General Secretary's Report

Personnel--The personnel of the office of the Union has remained unchanged, except that Miss Esther J. Tager resigned January 31, 1945, and Miss Hazel A. Bower was engaged February 1, 1945.

Financial report--On May 31, 1945, the total balance of all funds deposited with the Riggs National Bank, Chevy Chase Branch, was $13,451.34. Of this, $6,680 is in the Special Fund for use after June 30, 1945, and balance in the Bowie Medal Fund is $165.60. Accounts receivable, including dues in arrears, are about $2000, and bills payable about $3400. The General Secretary was instructed to prepare a detailed financial statement for the fiscal year ending June 30, 1945, for publication.

It was carried that bills receivable against E. M. Maggio for $5.75 for Transactions ordered in November and December, 1942, be written off as a bad debt.

Authority was given to transfer funds from unexpended budget items for (1) postage and communications and (2) stationery and miscellaneous in amounts of $300 and $250, respectively.

Membership--The total membership is now 2445 as against 2250 on December 12, 1944. Since the Twenty-Fifth Annual Meeting 370 new Members and Associates have been elected--257 since the Committee's meeting of December 12, 1944. Norman B. Keevil, of the Inactive List, was replaced on the Active List at his request, on January 1, 1945. Ten Members have been reported as having died since December 12, 1944: Carl George Carlson (May 6, 1944), O. N. Floyd (Nov. 30, 1944), Albert H. Horton (Mar. 4, 1945), Robert E. Horton (Apr. 23, 1945), Carl A. Ludy (Mar. 13, 1945), B. Ostrolenk (Nov. 26, 1944), G. W. Pickels (Dec. 2, 1944), Thomas Riggs (Jan. 16, 1945), Luther C. Smith, Jr. (killed in action Feb. 23, 1945), and Thomas H. Whitcroft (Dec. 18, 1944).

Twenty-four Members were transferred to the Inactive List at their requests, and 14 Members resigned.

In accordance with the action on December 12, 1944, 15 Members have been dropped because of arrears in dues. This action was approved with the understanding that, should it be found subsequently that any one of these named has been in the military service and desires to continue active membership, that person's name shall be replaced on the roll. There are seven Members known to be in the military service who are in arrears in dues, but they have not been dropped, in accordance with the action of the Executive Committee on December 12, 1944.

Fifteen Members were reported still in arrears for 1943 and 1944. Authority was given to continue all of these on the Active Roll, since some are already known to be in military service, but they are to receive no publications pending receipt of dues. Other unpaid dues include 64 for 1944 and 1945, and 338 for 1945.

The Manila Observatory, which was completely destroyed, has been supplied with a set of the Transactions available. This was approved.

A new List of Members and Officers as of May 15, 1945, is being prepared for early publication. (Note: It has been necessary to advance date of List to September 15, 1945.)

National Research Council--Reappointments and new appointments confirmed by the National Research Council for representatives of the American Geophysical Union on the Division of Foreign Relations were reported as follows: Thomas G. Thompson, J. E. Church, and H. U. Sverdrup.

The National Research Council advised that its budget for 1945-46 includes $400 for the work of the American Geophysical Union.

Publications--Parts II, III, and IV of the Transactions of 1944 have been received and distributed, and Parts V and VI are expected early in June.

Most of the papers for Part I (August, 1945) of Volume 26 of the Transactions have been received. The Transactions will continue to be published under the auspices of the National Research Council. The new format is being developed by the Editorial and Publication Committee.

Authority was granted to make application for second-class mailing privileges through the National Research Council and to pay the fee of $50.

International Union of Geodesy and Geophysics--Communications from abroad indicate considerable interest in the early revival of the activity of the International Union and there is a tentative plan for a meeting of its Executive Committee this summer or fall, probably in England.

Meetings--The Resolutions passed at the Twenty-Fifth Annual Meeting have been transmitted in accordance with the content of each. A number of favorable comments have been received. Most notable of these was the confidential one from the Secretary of War with regard to Resolution No. 6 on Microseisms, the contents of which cannot be revealed at this time. Much comment was received by mail regarding Resolution No. 7 on seismographic cooperation in the Western Hemisphere. Dr. John C. Merriam, President of the Pan-American Institute of Geography and History, suggested that perhaps some variation in procedure might result in a more extensive program. This was called to the attention of persons especially interested in this Resolution. Commodore Hellweg, in response to Resolution No. 8 on Time-Signal Service, states that there is some possibility of increasing the Time-Signal Service if there seems to be a demand and need for such increase.

The South Pacific Regional Committee of the Section of Hydrology held a meeting (the 17th Regional Meeting) in Los Angeles on February 27, 1945, with a program centered around the problems of permeability and infiltration of soils.

American Geological Institute--The material concerning the American Geological Institute was received and referred to the Special Committee [W. T. Thom, Jr. (Chairman), Ernst Cloos, and F. W. Reichelderfer] which was authorized on December 12. From the standpoint of the National Research Council, Chairman Ross G. Harrison advised that there seemed no reason why the American Geophysical Union should not adhere to the proposed American Geological Institute if it so chose.

Free Distribution of Publications--A Special Committee approved by the Executive Committee on June 29, 1944,has been appointed [C. A. Whitten (Chairman), Earl Ingerson, and Joseph B. Kincer, with Waldo E. Smith as ex-officio member].

National Roster--The work of assisting the National Roster in the preparation of monographs and other material relating to Geophysics has continued.

American Standards Association--G. C. Mattison was appointed as the Union's representative on the American Standards Association Committee.

The Humble Oil Company gravity-meter--George Woollard reported that he has an extensive program outlined for the use of the gravity-meter during the next several months that will take him over a circuit in the northern New England States and the Maritime Provinces of Canada.

Committees of the Union--The nomination of Joseph B. Kincer to replace Edgar Woolard on the Editorial and Publication Committee, recommended by the Executive Committee of the Section of Meteorology, was approved. Dr. Woolard finds his new duties in the Naval Observatory make it impossible to continue as Co-Editor.

The Committee on Membership has asked instruction regarding a proposal for membership as Associates of high school students and recent graduates who have not had college degrees, but who are engaged in work related to Geophysics. It was agreed that the proposed revision of the Statutes and By-Laws should be flexible enough to permit consideration in such cases.

Items of Interest--The late Dr. Robert E. Horton, Member of the Union since 1930 and active in the Sections of Hydrology and Meteorology, made certain provisions for bequests from his residual estate for the Section of Hydrology of the Union. It may be some time before we will know just what this means, because of probation of the will and because no part of the estate is available during the lifetime of Mrs. Horton, excepting for $5,000 which is a bequest to finish some of the work of himself and colleagues under certain specific conditions.

Action on General Secretary's Report--Matters in the General Secretary's report, not already specifically acted upon as indicated above, were accepted and approved.

Reports of Standing Committees

Membership--Chairman Johnston referred to the qualification of Associates, namely, active interest in physical processes of the Earth or technical assistance in the application of geophysics with a minimum requirement of a college degree in some field of geophysics or allied science or a comparable period of training and experience. He reported that on these instructions the Committee felt it necessary to take unfavorable action on the application of an 18-year-old girl strongly sponsored by two Members. He noted also that the clause in the proposed Statutes and By-Laws would permit, if passed, the Committee to recommend election as an Associate of any person who has an active interest in geophysics, and so give more consideration to candidates of this type.

The resignation of J. A. Duerksen as one of the Committee on Membership has been accepted with regret, and James B. Small has been appointed in his place to represent Geodesy.

Statutes and By-Laws--Chairman Harradon presented the report of the Committee(see Appendix C of the Minutes of Business Meeting) with copies of the proposed Statutes and By-Laws and expressed the hope that it would be possible to authorize the General Secretary to submit the proposed revision promptly for a mail vote of the Union for adoption by July 31, 1945. After extended discussion, it was moved, seconded, and carried that the proposed revision of the Statutes and By-Laws be considered in detail by members of the Executive Committee, that each one of the Executive Committee submit comments to the General Secretary by June 10, and that a special meeting of the Executive Committee be called for June 16, 1945, to put the proposed Statutes and By-Laws in form for mail ballot to close July 31, 1945. [Note: One prime point of the discussion concerned Article 7 on Elections; there was considerable feeling that provision be made for elections by mail or at least mail balloting be permitted for any Section so desiring, provided the Executive Committee of the Union first gave approval.]

Budget--Chairman Swick read the report of the Committee on Budget (see Appendix 1) and upon motion duly seconded, the budget as proposed for the year ending June 30, 1946, was adopted. The question raised as regards increase of annual dues to $5 effective January 1, 1946, was deferred for further consideration at the meeting to be held June 16, 1945.

The General Secretary made short oral reports for the Committee on Meetings and for the Editorial and Publication Committee.

Reports of Special Committees

Geophysical and Geological Study of Continents--Chairman Thom briefly abstracted his Committee's report.

Audit--In the absence of Chairman McNish, the General Secretary noted the report made earlier at the Business Session to the effect that the books had been kept in good condition and that the Committee had complimented the way in which the books were kept and had stated that the accounts, as briefly summarized in the General Secretary's report, were correct in all particulars. The report and statement (see Appendix 2) were accepted and approved.

Award of William Bowie Medal--Chairman Bucher mentioned that in the first balloting eight out of nine members of the Committee had cast their votes for Dr. Jakob A. B. Bjerknes, and that in the second ballot the vote was unanimous.

American Geological Institute--Chairman Thom presented the report (see Appendix 3) and recommendation of this Special Committee. The report was accepted and approved. Motion was also made, seconded, and carried that the President appoint representatives of the Union to attend the next called meeting of the Organizing Committee of the American Geological Institute when an invitation is received.

Free Mailing--Chairman Whitten's report (see Appendix 4) was accepted and approved, with the understanding that the question of free distribution of the Union's publications would be subject to subsequent review and revision.

Section Matters

Seismology--President Stechschulte reported that in February, 1945, Secretary Blake had asked to be relieved and accordingly the Executive Committee of the Section had designated Leonard M. Murphy as Acting Secretary.

Meteorology--President Reichelderfer spoke of the desirability of getting bibliographic service started by the Union. It was moved and carried that, recognizing the need in many branches of science for a more complete bibliography of meteorology and not only a bibliography of past papers but also a continuing bibliographic service, the Union and the National Research Council lend support to the establishment of such a service as soon as possible, and that a letter of representation be made by the Executive Committee to National Research Council for that purpose.

Hydrology--President J. E. Church reported the Section's request that Richard A. Hertzler be designated the Union representative of the Section of Hydrology to the Association of American Foresters. The request was approved.

There were no matters presented by the Sections of Geodesy, Terrestrial Magnetism and Electricity, Oceanography, Volcanology, and Tectonophysics.

A motion was made and carried that any duly recorded reports previously listed in these minutes and not acted upon be accepted and placed on file.

New Business

The General Secretary reported inquiries from time to time concerning a fee for Life Membership in the Union; this matter was referred to the Committee on Statutes and By-Laws.

The General Secretary reported four queries submitted by H. T. Stetson with regard to the raising of funds for the work of Special Committees of the Union, namely: (1) May any Special Committee solicit funds for investigations? (2) If so, what approval is required for authority of campaign under (1)? (3) Should not there be appointment of a Special Committee (to include the General Secretary ex officio) to determine method and assignment of such funds? (4) How should allotments from such funds be controlled by the Executive Committee of the Union? The matter was left for later consideration.

The Executive Secretary stated that several persons had suggested the preparation of a complete index of the Transactions. It was agreed that such an index is desirable, would be valuable, to Geophysics, would advance the interests of the Union, and should be undertaken when the opportunity permits.

The meeting adjourned at 18^h.

J. A. FLEMING,
General Secretary
WALDO E. SMITH,
Executive Secretary

APPENDIX 1--REPORT OF COMMITTEE ON BUDGET, 1945-46

C. H. Swick, Chairman
R. W. Goranson H. N. Eaton

The following proposed budget for the fiscal year 1945-46 is submitted by the Committee on Budget, for the fiscal year July 1, 1945 to June 30, 1946.

Budget for fiscal year ending June 30, 1946

Expected receipts		
Balance in bank, June 30, 1945	$10,500 [a]	
Dues 2,400 (net[b]) Members for 1946	7,200	
Grant National Research Council	400	
Grant Rockefeller Foundation account	7,000 [c]	
Sales *Transactions* and reprints, etc.	2,000	
Bills receivable including dues in arrears	1,300 [d]	
Total estimated receipts		$28,400
Deduction for reserve, Special Fund[a]		3,400
Net estimated available receipts		$25,000
Authorized expenditures		
Transactions, 3 numbers Volume 26 and 3 numbers Volume 27 (800 ± pages) including services IBM operator	$ 5,600	
List of Members and Officers	500	
Bibliography of Hydrology, 1941-1945	500	
Services Executive Secretary	5,000	
Services three clerks	5,400	
Expenses 27th Annual Meeting	500	
Expenses Regional Meetings	100	
Expenses Sections	100	
Expenses Committees	250	
Honoraria to Co-Editors	1,500	
Postage and communication	850	
Stationery and miscellaneous	500	
Bowie Medal	20	
Travel	300	
Office equipment	300	
Bills payable other than those estimated in arriving at balance in bank, June 30, 1945	80	21,500
Estimated balance June 30, 1946		$ 3,500 [e]

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[a] Of this reserve one-third ($3,400) of Special Fund received from Members must be reserved for fiscal year 1946-47.

[b] Increase of membership in 1945 indicates our rolls may reach 2,800 in 1946, but effects of war causing resignations, transfers to Inactive List, and non-payment of dues makes it wise to set expected net of dues as for 2,400 Members. [See p.171 re increase in dues beginning Jan. 1, 1946.]

[c] To be requisitioned in four quarterly installments; this will leave balance of $7,000 available in grant for following year.

[d] This item assumes that a certain part of unpaid past dues will not be paid because of resignations, overseas duty, transfers to Inactive List, and dropping of any becoming two years in arrears.

[e] In addition to this balance there will also be a cash reserve balance in the Special Fund of $3,400, as indicated under footnote (a) or an actual total estimated balance of $6,900.

It should be noted that the grant from the Rockefeller Foundation will expire on July 1, 1947, and the Special Fund will be exhausted at the same time. Additional income will therefore be needed after that date. No definite figures are available for a full year's expenditures since the reorganization of the Union about a year ago. The total disbursements for the calendar year 1944 were approximately $18,000, and these included about one-half year's operations under the new organization plan. The adopted budget for the fiscal year 1944-45 authorized expenditures of $20,000, and the above proposed budget for the fiscal year 1945-46 is for $21,500. Under present conditions these budgets can be met without use of the normal reserve funds of the Union.

After the expiration of the Rockefeller Foundation grant and the exhaustion of the Special Fund, it will be necessary to provide about $10,000 additional annual income. One way of doing this is, of course, to increase the dues. For the next fiscal year the expected income from dues is $7200 from 2400 Members. By July, 1947, the Union may probably expect a membership of about 3000. If the dues are increased to $5.00, the expected income from dues will be $15,000, or $7,800 above the expected income from this source during the next fiscal year. This will still fail to meet the deficiency in income by about $2000.

The Budget Committee would prefer not to make a definite recommendation in this matter. The question will undoubtedly require very careful consideration by the Executive Committee.

The Budget Committee wishes to call attention to the desirability of having the accounts of the Treasurer changed, if possible, from a calendar-year to a fiscal-year basis. Under the present arrangement it is very difficult to determine the relationship of disbursements on the calendar-year basis with the authorized budget on a fiscal-year basis.

APPENDIX 2--REPORT OF SPECIAL COMMITTEE ON AUDIT FOR CALENDAR YEAR 1944

A. G. McNish (Chairman), R. H. Weightman

Your Special Committee on Audit reporting as of May 24, 1945, has made an examination of the accounts of the American Geophysical Union for the calendar year ending December 31, 1944. It finds that the statement of the General Secretary, attached hereto. is correct as given and is in agreement with the books of the American Geophysical Union. Due correction has been made in the books for 1944 and the errors resulting from failure to enter two checks under disbursements during the calendar year ending December 31, 1943. (See report of Special Committee on Audit for calendar year 1943, *Transactions* of 1944, Part II, page 367.) Your committee has found that the records have been excellently kept, that all receipts and disbursements are duly substantiated and that the methods of handling the accounts are clear and efficient.

Financial Statement January 1 to December 31, 1944

Receipts			
Cash balance, January 1, 1944, as reported from December 31, 1943			$10,247.71
American Geophysical Union		$5,633.34	
Special Fund		2,905.00	
Bowie Medal Fund		195.60	
Washington Assembly		1,513.77	
Dues, 1941, 1942, 1943, 1944, 1945, 1946			6,418.33
1941		$ 3.00	
1942		39.00	
1943		196.00	
1944		5,948.00	
1945		217.50	
1946 et seq		14.83	
Sales of Publications			3,773.00
Transactions		$1,280.52	
Reprints		2,460.14	
Bibliography of Hydrology		16.14	
List of Members and Officers		1.90	
Exhibit Maps		11.60	
Proceedings Geodesy, Washington Assembly		2.70	
Special Fund			7,116.00
Contributions in 1944		$2,096.00	
Transfers by Executive Committee		5,020.00	
June 2, 1944 (General Fund charged to Publication sales)	$3,500.00		
June 29, 1944 (General Fund charged to Publication sales)	6.23		
June 29, 1944, balance Washington Assembly	1,513.77		

Receipts--Concluded		
Special Fund		
National Research Council		$ 399.50
Rockefeller Foundation		3,000.00
Miscellaneous		0.95
Total receipts ($10,247.71 + $20,707.78)		$30,955.49
Disbursements		
Transactions of 1943		$ 3,713.41
Reprints (1943)		1,173.16
Transactions of 1944		1,074.31
Expenses of General Secretary's office		4,919.95
Services, including withholding tax to September 30, 1944	$4,465.21	
Equipment	319.25	
Miscellaneous	135.49	
Transfers to Special Fund by Executive Committee		5,020.00
June 2, 1944 (General Fund charged to Publication sales)	$3,500.00	
June 29, 1944 (General Fund charged to Publication sales)	6.23	
June 29, 1944 (Balance of Washington Assembly fund as of January 1, 1944)	1,513.77	
Committees		251.39
Finance	$ 17.25	
Membership	158.83	
American Geological Institute	34.32	
Executive Committee	40.99	
Sections		105.82
Geodesy	21.91	
Seismology	15.78	
Meteorology	22.90	
Terrestrial Magnetism and Electricity	1.95	
Oceanography	1.80	
Volcanology	1.80	
Hydrology	30.00	
Tectonophysics	1.90	
Berkeley Regional Meeting Account	7.78	
Annual Meeting		586.34
Postage, express, telephone, and telegraph		791.07
Stationery, supplies, and miscellaneous		480.80
Bowie Medal		$ 20.00
Total disbursements		$18,136.25
Balance December 31, 1944		$12,819.24

Riggs National Bank, Chevy Chase Branch, as of December 30, 1944		$13,132.60
Less checks outstanding: No. 1395	$10.29	
1397	70.35	
1398	106.10	
1399	61.00	
1401	7.47	
1402	1.90	
1403	56.25	
Total checks outstanding		313.36
Balance December 31, 1944, as above		$12,819.24

Distribution of balance

American Geophysical Union	$12,643.64 [a]	
Bowie Medal Fund	175.60	
		$12,819.24

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[a] Of this amount, two-thirds of the Special Fund of $10,021, or roughly $6,680 is to be held intact for expenditures subsequent to June 30, 1945.

Bills receivable

Publications		$ 253.14
Transactions	$163.75	
Reprints	84.84	
Miscellaneous	4.55	
Dues		583.00
Postponed account, 9 Members in enemy countries	$ 96.00	
Unpaid account, 25 Members for three years, 1942-44	75.00	
Unpaid account, 35 Members for two years, 1943-44	70.00	
Unpaid account, 114 Members for one year, 1944	342.00	
National Research Council allotment, fiscal year 1945		400.00
Rockefeller Foundation grant, balance of $6,000, requisitioned for fiscal year ending June 30, 1945		3,000.00
Total bills receivable		$ 4,236.14

Bills payable

Mr. Davies, National Research Council, multigraphing letterheads	$ 14.00
Kirby Lithographic Co., Inc., for Parts I, II, III, and IV, Transactions of 1944 (approx.)	3,370.00
Reprints, advance payment	380.34
Collector of Internal Revenue, withholding tax, 4th quarter, 1944	386.19
Batt, Bates, for mimeographing	13.00
C. and P. Telephone Co., rental and calls	14.58
Kirby Lithographic Co., Inc., for labels	45.08
Reilly for glass top	13.72
Stott for supplies	8.57
Columbia Planographing, for letters and directory cards	29.79
Royal Typewriter Co., for supplies and repairs	4.75
Cosmos Club, use of meeting rooms	4.00
Total bills payable	$ 4,284.02

Recapitulation

	A. G. U.	Bowie Medal Fund
Cash balances	$12,643.64	$175.60
Bills receivable	4,236.14	0.00
	$16,879.78	$175.60
Bills payable	4,284.02	0.00
Net balance	$12,595.76	$175.60

Cost of equipment owned by American Geophysical Union

One 18-inch large primer Burroughs typewriter, serial No. 50A232450	$190.80
One 10-inch elite Royal typewriter, serial No. KHM-2076351	100.31
Two 4-drawer, 5×8-inch steel filing cases (gift)	0.00
Two steel posture chairs	22.00
One Globe-Wernicke, 2-pedestal, flat-top steel desk, 60×34 inches	49.18
One Triner postal scale, 4 lbs. by 1/2 oz.	16.20
One Arrow stapler	6.75
One walnut flat-top desk, No. 2, and $15.43 for glass top	95.43
One walnut typewriter desk, No. 3, and $13.72 for glass top	100.72
One walnut typewriter desk, No. 4, and $13.72 for glass top	89.72
One walnut chair	21.50
1 costumer, walnut finish	3.50
6 desk trays, walnut finish	8.60
One 15-inch Eastman trimmer	13.50
Total cost of equipment	$718.21

APPENDIX 3--REPORT OF SPECIAL COMMITTEE TO STUDY THE AFFILIATION OF THE AMERICAN GEOPHYSICAL UNION WITH THE PROPOSED AMERICAN GEOLOGICAL INSTITUTE

W. T. Thom, Jr., Chairman
Ernst Cloos F. W. Reichelderfer
L. H. Adams, Ex officio

The Special Committee to Study the Affiliation of the American Geophysical Union with the Proposed American Geological Institute, after lengthy deliberation and discussion, offers the following recommendation:

The American Geophysical Union is in accord with proposals of the proposed Institute, as set forth in Article II of the draft constitution.

The Committee understands that the Geological Society of America has suggested, as an alternative to the formation of an "American Geological Institute," the organization of a "coordinating committee" to be composed of representatives of the organizations cited in the proposed constitution, and that it has underwritten its expenses. This "coordinating committee," suggested by the Geological Society of America, would serve as a "pilot organization" for a limited period and would explore "Institute" objectives and the ways and means for attaining them.

Such a trial approach toward the development of the projected Institute seems a wise one, in view of the complex problems to be dealt with, and your Special Committee therefore recommends that the American Geophysical Union favor this more conservative solution of the matter, suggested by the Geological Society of America, provided that this alternative suggestion is acceptable to the proponents of the organization of the American Geological Institute.

APPENDIX 4--REPORT OF SPECIAL COMMITTEE ON FREE MAILING

C. A. Whitten, Chairman
Earl Ingerson Joseph B. Kincer
Waldo E. Smith, Ex officio

The Special Committee on Free Mailing of the Transactions has given consideration to some of the problems dealing with the circulation of the Transactions and makes the following recommendations:

We recommend that the price of the Transactions be $1.50 per part or $7.50 for a set of six parts for a calendar year. The price of a set of three parts for the balance of 1945 would be $3.75.

We also recommend that libraries be given the same discount rate for the purchase of a set of the Transactions as that given to Members of the Union (33-1/3 per cent discount).

We also recommend the revision of the policy of free mailing by abolishing the present domestic lists and re-establishing these lists after all persons and institutions have been notified of the change of policy and have been given the opportunity to become Members of the Union or to purchase sets of the Transactions.

Minutes of June 16, 1945

The meeting was called to order at $09^h\ 30^m$, June 16, 1945, by President Adams in the Board Room of the building of the National Academy of Sciences and National Research Council, Washington, D. C. (During temporary absence of the President from $13^h\ 10^m$ to $15^h\ 45^m$, Vice-President Bucher presided.)

Present--Twenty-six persons were present, namely: L. H. Adams, K. H. Beij, W. H. Bucher, Ernst Cloos, J. A. Duerksen, C. J. Fish (alternate for H. U. Sverdrup), J. A. Fleming, H. D. Harradon, W. G. Hoyt (alternate for J. E. Church), Earl Ingerson, H. F. Johnston, D. G. Knapp, W. D. Lambert, J. P. Marble, A. G. McNish, L. M. Murphy, Frank Neumann, I. Roman, W. W. Rubey, W. L. Schmitt, Waldo E. Smith, W. D. Sutcliffe, C. H. Swick, T. P. Thayer (alternate for R. E. Fuller), R. H. Weightman (alternate for F. W. Reichelderfer), and C. A. Whitten.

The following were excused because of absence from the city or previous engagements: J. E. Church, R. M. Field, N. H. Heck, M. K. Hubbert, L.L. Nettleton, F. W. Reichelderfer, V. C. Stechschulte, H. T. Stetson, H. U. Sverdrup. Hazel A. Bower of the office of the Union was also present to take notes.

The General Secretary informed the meeting of the hospitalization at Norwood, Massachusetts, of R. M. Field because of an automobile accident and that, at last account, he was recovering; it was unanimously agreed that the General Secretary write Dr. Field appropriately on behalf of the Executive Committee.

Minutes of Meeting of June 1, 1945--The minutes of the meeting of June 1 were read in abstract and were approved for publication in Part I of the Transactions of 1945.

General Secretary's Report

Personnel--The resignation of Mrs. Jessie C. Grange, effective June 30, 1945, was reported.

No financial, membership, or other reports were presented by the General Secretary except as follows:

International Union of Geodesy and Geophysics--A meeting of the Executive Committee of the International Union of Geodesy and Geophysics is planned for Oxford, England, to be held later in 1945 or early in 1947.

It was agreed that any representatives of the American Geophysical Union in attendance should be guided, as regards any actions involving policy or expression of opinion of the American Geophysical Union, according to their best judgment of the discussions at the Oxford Meeting.

Special Committee on Precise Surveys and Maps--In accordance with the report of Chairman Swick it was carried to drop the word "Precise" and have the Committee designated hereafter as "Special Committee on Surveys and Maps."

C. H. Swick was designated as representative of the American Geophysical Union at the Fifth Annual Meeting of the American Congress on Surveying and Mapping scheduled for June 22, 1945, in Washington, D. C.

International Astronomical Union--This Union was reported as becoming active and losing no time in getting its work under way again following the cessation of hostilities in Europe.

Petition for establishment of Tennessee Basin Branch--The request dated February 22, 1945, of 17 Members in the Tennessee Valley for authority to establish a Tennessee Basin Branch of the Union in the area conforming to the Tennessee River Basin was reported.

Reports of Committees

Committee on Free Mailing--Chairman Whitten presented a report (see Appendix 1) which was amended and accepted.

Committee on Resolutions--Chairman Ingerson presented a Resolution of Thanks to the Carnegie Institution of Washington; this Resolution was unanimously adopted (see Appendix 2).

Unfinished Business

Increase in dues--It was unanimously agreed that the annual rate of dues to Members and Associates be increased to $5 effective January 1, 1946, and that suitable advice be sent all Members and Associates to this effect.

Statutes and By-Laws--The draft of revised Statutes and By-Laws as recommended June 1, 1945, by the Standing Committee on Statutes and By-Laws was discussed in detail as read by Chairman Harradon article by article. Comments on the proposed revisions, as received from Members of the Executive Committee in accordance with action taken at the meeting of June 1, 1945, were presented in summary and each comment or suggestion was discussed.

The final form for each Article and Section of the Statutes was adopted, subject to the approval of the National Research Council, and the General Secretary was instructed, after approval of the Council and any necessary editing, to prepare a ballot to be mailed on or before July 1, 1945, to all the membership of the Union for vote on final adoption of the Statutes as of July 31, 1945.

The recommendations as regards the By-Laws were then similarly discussed item by item as read by Chairman Harradon. Comments received from Members of the Executive Committee were presented in summary and each comment or suggestion was discussed.

The final form for each By-Law was adopted, subject to the approval of the National Research Council, and the General Secretary was instructed, after approval of the Council and any necessary editing, to prepare for mail ballot, to be mailed on or before July 1, 1945, to all of the membership of the Union for vote on final adoption of the By-Laws as of July 31, 1945. [See pp. 172-177.]

New Business

Tennessee Basin Branch--Subject to majority vote in favor of revised Statutes and By-Laws, the General Secretary was instructed to advise the petitioners for the establishment of a Tennessee Basin Branch of the Union that a Tennessee Basin Branch of the Union is authorized to be effective upon date of organization meeting and naming of officers.

Adjournment--There being no further business the meeting was adjourned at 16^h06^m.

J. A. FLEMING,
General Secretary

WALDO E. SMITH,
Executive Secretary

APPENDIX 1--REPORT OF SPECIAL COMMITTEE ON FREE MAILING

C. A. Whitten, Chairman
Earl Ingerson Joseph B. Kincer
Waldo E. Smith, Ex officio

The Special Committee on Free Mailing of the *Transactions* has given further consideration to some of the problems concerning the distribution of the *Transactions*. The Committee recommends that certain policies be established in regard to free mailing.

In view of the change of publication from annual *Transactions* to a bimonthly journal form the Committee feels that this is the proper time to change the policy with respect to domestic libraries. In general, libraries of governmental agencies, State universities, and privately endowed institutions can afford to subscribe to the *Transactions* at the rate established by previous action. Exceptions to this rule should include the libraries of the National Research Council, and the Department of Terrestrial Magnetism. Further exceptions should include such individuals as Dr. C. H. Marvin, President, George Washington University, Dr. Vannevar Bush, President, Carnegie Institution of Washington, and the Director of the Pan American Union. These libraries and individuals should be included on the free-mailing list in appreciation of services rendered to the Union. The names of other libraries and individuals could be added to the free-mailing list as the need arises. The Committee recognizes the fact that the Union should assist in the educational program of universities and colleges. Therefore, we suggest that a limited number of copies be available for distribution to the libraries of institutions which teach subjects dealing with and related to geophysics and are not able to subscribe because of limited funds. The domestic free-mailing list prior to action of June 1, 1945, contained about 100 names of libraries and individuals. The Committee believes that about 75 of these will become subscribers.

The Committee favors the adoption of an exchange policy with other publications but would not recommend active solicitation of such until the Union has adequate library facilities.

The present free-mailing list for foreign distribution contains between 150 to 200 names some of whom have never received any copies and very few who have received any copies since the war started. The Committee recommends that 400 copies be set aside for foreign distribution, such to be made when conditions have become more stable and it is possible to re-establish the foreign free-mailing list.

Although not specifically charged with the responsibility of determining the number of copies of the Transactions to be printed, the Committee suggests that the edition of Part I, 1945, be 3,500. A break-down of this figure is: Members, 2,445; new Members, 200; libraries, etc., 75; foreign, 400; and reserve, 380. The members of the Committee feel that they are not too optimistic in suggesting that number.

APPENDIX 2--REPORT OF SPECIAL COMMITTEE ON RESOLUTIONS

Earl Ingerson, Chairman
N. H. Heck J. P. Marble

The Special Committee on Resolutions recommends that the following Resolution be adopted:

RESOLUTION OF APPRECIATION TO THE CARNEGIE INSTITUTION OF WASHINGTON

WHEREAS, The Carnegie Institution of Washington has for these many years extended facilities to the American Geophysical Union in the provision of space for office and storage at the Institution's Department of Terrestrial Magnetism, and

WHEREAS, This courtesy has greatly facilitated the work of the Union, and

WHEREAS, The operating expenses of the Union have been very materially reduced thereby, therefore be it

RESOLVED, That the American Geophysical Union express its grateful appreciation to the Carnegie Institution of Washington for these most helpful facilities, and be it further

RESOLVED, That copies of this Resolution be sent to the President of the Carnegie Institution and to the Chairman of its Board of Trustees.

REVISED STATUTES AND BY-LAWS, EFFECTIVE JULY 31, 1945

The revision of the Statutes and By-Laws of the American Geophysical Union proposed by the report of the Committee on Statutes and By-Laws, after authority of the Executive Committee [pp. 148, 171] and after approval by the National Research Council, was printed and copies were mailed on June 30, 1945, to each Member and Associate. An accompanying explanatory letter with form of ballot was enclosed.

Nine hundred and twenty-five votes were received on or before the designated closing date, namely, July 31, 1945. Nine hundred and eight were for adoption without change or comment, eight were partly or wholly unfavorable, and nine were unmarked. Most of the unfavorable votes suggested only minor editorial changes to correct possible ambiguities. Consideration was given to all of the few suggested editorial changes in consultation with the Chairman of the Committee on Statutes and By-Laws. Those changes deemed appropriate were made as authorized by the Executive Committee [p. 171].

The finally amended and adopted Statutes and By-Laws effective July 31, 1945, and overwhelmingly approved by the mail vote, are printed on pages 173-177.

NATIONAL RESEARCH COUNCIL

AMERICAN GEOPHYSICAL UNION

STATUTES AND BY-LAWS

(Originally adopted at organization in 1919 and as amended to July 31, 1945)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Union of Geodesy and Geophysics and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council.

STATUTES

Article 1: Objects--(a) To assist in carrying out the objects of the International Union of Geodesy and Geophysics, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and coordinate researches which depend upon international cooperation, and to provide for their scientific discussion and publication; and to facilitate special researches.

(b) To promote, coordinate, and facilitate the study of the various branches and interrelationships of geodesy and geophysics in the United States of America, its outlying territories, and the ocean; to provide for scientific discussion, publication, and dissemination of information relative to these fields through the Transactions of the American Geophysical Union and other means.

Article 2: Bequests, Grants, Contributions, and Funds--The Union, upon approval of the National Research Council, may receive bequests, grants, contributions, and funds and may make disbursements therefrom, upon approval of the National Research Council.

Article 3: Membership--The membership of the American Geophysical Union shall be as follows:

(a) Members--(1) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(2) Citizens of the United States of America engaged in geophysical research or its applications, elected by the Executive Committee of the American Geophysical Union.

(3) Nationals of other countries having the same qualifications, elected by the Executive Committee of the Union; these may not vote or be officers of the Union or of its Sections, or delegates of the Union to International Assemblies or Meetings.

Members in good standing for a total of 15 years shall, following retirement from active professional service because of age and upon advice to the General Secretary, be extended the complete privileges of members without further payment of dues.

(b) Members ex officio--(1) The Chairmen of the following Divisions of the National Research Council: Foreign Relations; Physical Sciences; Chemistry and Chemical Technology; Geology and Geography; and Biology and Agriculture.

(2) Officers of the International Union of Geodesy and Geophysics and of its Associations, who are citizens of the United States of America.

(c) Corresponding Members--Nationals of other countries, outstanding in the field of geophysics, elected by the Executive Committee of the American Geophysical Union; they shall not pay dues but shall enjoy the privileges of Members except that they may not vote or be officers of the Union or of its Sections or delegates of the Union at International Assemblies or Meetings.

(d) Associates--Citizens of the United States of America other than those eligible for regular membership under Article 3, Sections (a) or (b), whose interest in Geophysics is deemed by the Executive Committee of the Union to warrant their election. Associates shall enjoy the privileges of Members except that they may not be officers of the Union or of the Sections, or be delegates of the Union at International Assemblies or Meetings.

(e) Corporation Members--Corporations and other organizations interested in geophysics, elected by the Executive Committee of the Union. The designated representative of each such organization shall enjoy the privileges of a Member.

Article 4: Sections--The American Geophysical Union shall consist of Sections as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; (f) Volcanology; (g) Hydrology; and (h) Tectonophysics.

Members, Corresponding Members, Associates, and Corporation Members shall designate the Section, or Sections, with which they desire to be affiliated. The function of the Sections, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

Article 5: Officers of the American Geophysical Union--The officers of the American Geophysical Union shall consist of a President, a Vice-President, and a General Secretary, whose terms of office shall expire June 30, 1947, but terms of office effective July 1, 1947, shall be for periods of three years, with the limitation that the President and Vice-President shall not be eligible for immediate reelection; in case any office becomes vacant, the Executive Committee of the Union shall designate a successor in office to complete the term. These officers shall be elected by mail ballot.

The General Secretary shall act also as Treasurer and shall receive and disburse all dues, grants, and funds otherwise received as authorized by the Executive Committee of the Union; his accounts shall be audited annually by a Committee on Audit.

The Executive Committee of the Union may employ an Executive Secretary, who shall be directly responsible to the General Secretary.

Article 6: Officers of Sections--The officers of each Section of the American Geophysical Union shall consist of a President, a Vice-President, and a Secretary, whose eligibility and periods of office shall correspond to those of the Union as indicated under Article 5. These officers shall be elected by mail ballot. In case any office becomes vacant the Executive Committee of the Section concerned shall designate a successor in office to complete the term. The President of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

Article 7: Executive Committees--The Executive Committee of the Union shall consist of the President, the Vice-President, and the General Secretary of the Union, and of the President or his designated representative and Secretary of each Section of the Union, the last past Presidents of the Union and of the Sections, Chairmen of the Standing Committees of the Union; and, in addition, ex officio, the Executive Secretary of the Union, those officers of the International Union of Geodesy and Geophysics and of its Associations who are citizens of the United States of America, and the Chairman of each of the following Divisions of the National Research Council: Foreign Relations; Physical Sciences; Chemistry and Chemical Technology; Geology and Geography; and Biology and Agriculture.

This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Union of Geodesy and Geophysics. The Executive Committee of the Union, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the Assemblies and Meetings of the International Union of Geodesy and Geophysics and of its Associations, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

There shall be an Executive Committee of each of the Sections of the Union which shall include at least the President, Vice-President, and the Secretary and the last past President of the Section.

Article 8: Annual Meetings--The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union.

Article 9: Special Meetings--Special meetings of the American Geophysical Union, of any Section or of any group of Sections, and of any Local or Regional Branch may be called by the respective Presidents with the advice of the respective Executive Committees; notification of such meetings must be communicated promptly to the office of the General Secretary of the Union.

Article 10: Branches of the Union--Local or Regional Branches of the Union may be established on the approval of the Executive Committee of the Union. These Branches shall be organized along the general lines of the Union, shall be responsible to the Executive Committee of the Union, and shall duly report their activities through the General Secretary.

Article 11: Publications--The official publication of the Union shall be the Transactions of the American Geophysical Union published under the auspices of the National Research Council of the National Academy of Sciences. Control of matter to be published in the Transactions shall rest in an Editorial and Publication Committee composed of at least one Member from each Section, designated by the Executive Committee of the Section which he represents and appointed by the President of the Union. The General Secretary of the Union shall be ex-officio Chairman and the Executive Secretary of the Union shall be ex-officio Secretary. The Editorial and Publication Committee shall have responsibility (a) of acceptance, editorial revision and condensation, or rejection of any material submitted for publication in the Transactions and (b) as regards any special publications subject to the approval of the Executive Committee of the Union.

Non-members of the Union may subscribe to the Transactions, and purchase individual copies thereof, as well as other publications of the Union at rates approved by the Executive Committee of the Union.

Article 12: By-Laws--The American Geophysical Union is authorized to enact such By-Laws as may be necessary for the performance of its functions and duties.

Article 13: Amendments--(a) Any Member, Associate, or Corporation Member may propose an amendment to the Statutes or By-Laws, which after consideration by the Committee on Statutes and By-Laws and upon approval by the Executive Committee of the Union, shall be submitted for vote to the membership of the Union.

(b) After 30 days' notice has been given, amendments to the Statutes or By-Laws shall be voted on by mail. They require for adoption a majority vote of the membership voting.

(c) Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

(1) The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

(2) Members of the Union, in classes (a) and (d) of Article 3 of the Statutes, shall pay dues not to exceed $5 for each calendar year, the amount for each year to be fixed by the Executive Committee of the Union; Members of class (e) shall pay dues of $100 for each calendar year; any other Member or Associate, on payment of $100 at any time, shall be relieved of further payment of dues.

(3) Standing Committees shall be as follows: Statutes and By-Laws; Membership; Meetings; Nominations; Budget; Audit; and Editorial and Publication.

(4) Special Committees shall be established from time to time, as need arises, to consider special matters approved by the Executive Committee of the Union.

(5) Appointments to Committees of the American Geophysical Union shall be made by the President or President-Elect and appointments shall terminate at the end of the fiscal year for which they are made, unless otherwise specifically designated; no appointment shall extend, however, beyond the term of office of the appointing President or President-Elect.

(6) Meetings of the Union shall be called at least 30 days in advance, and those present at the meeting shall constitute a quorum.

(7) Meetings of the Executive Committee of the Union shall be called by the President at least 15 days in advance, and a minimum of 12 shall constitute a quorum.

(8) Final action on matters affecting any Section specifically shall not be taken by the Executive Committee of the Union when that Section is not represented.

(9) Statutes and By-Laws adopted by a Section or Branch shall not conflict with the provisions of the Statutes and By-Laws of the Union.

(10) Matters pertaining solely to a Section and not to the Union as a whole, shall be acted upon by the Section concerned.

(11) No mail ballot of the Union shall be closed until at least 30 days after date of issue.

(12) Officers, designated by the Executive Committee of the Union or the Executive Committee of any of its Sections, to fill uncompleted terms, shall not hold office without election after expiration of the period for which their predecessors were elected.

(13) Removal from the rolls, other than by resignation, of a Member, Corresponding Member, Associate, or Corporation Member of the American Geophysical Union shall be made only upon a three-fourths vote of a quorum of the Executive Committee of the Union; Members, Associates, and Corporation Members who fail to pay dues for two consecutive years shall be reported to the Executive Committee by the General Secretary with recommendation that their names be removed from the Union's rolls.

(14) Under special circumstances and upon request to the General Secretary any Member or Associate may be transferred to an Inactive List of the Union without further payment of dues and without other privileges as Member or Associate but reinstatement may be made upon request and payment of current year's dues.

Reelection of Members and Associates who have been dropped from the rolls by action of the Executive Committee of the Union may be effected only after filing a signed application under the usual procedure for election of Members and Associates.

(15) The Executive Committee of the Union may arrange, either through bequests, special contributions, grants, or other funds of the Union, for awards, medals, honoraria, or certificates of merit to geophysicists in recognition of meritorious work or service in the field of the whole Union or in the field of any of its several Sections, and for scholarships, fellowships, or grants-in-aid to assist worthy candidates in the advancement of geophysical science.

(16) The Executive Committee may appoint Union or Section representatives to other organizations, upon mutual agreement, when such representation may promote coordination and interest in geophysics. The Executive Committee of the Section concerned shall make tentative arrangements for interorganization-relationships and make selections of representatives of the Sections. Arrangements and commitments must be ratified by the Executive Committee of the Union before they are binding on the Union.

(17) The duties of the President shall be those ordinarily appertaining to this office; he shall preside at the meetings of the Executive Committee and at General Meetings of the Union, shall appoint members of Standing and Special Committees; in the absence or disability of the President, the Vice-President shall carry out the duties ordinarily performed by the President. The more important letters, and especially those concerned with policy of the Union, shall be signed by the President or the General Secretary in accordance with rules, precedents, and decisions of the Executive Committee of the Union.

(18) The General Secretary elected by the Union shall be responsible to the Executive Committee of the Union for the general administration of the Union's activities as determined by the Executive Committee of the Union. He shall exercise general supervision over the Executive Secretary, serve without honorarium, receive and disburse funds for the Union in accordance with the instructions of the Executive Committee of the Union, and provide a surety bond, in a sum set by the Executive Committee of the Union and at the expense of the Union, for funds of the Union in his control. He shall sign checks as General Secretary on the account of the American Geophysical Union with a depository approved by the Executive Committee of the Union; in his absence the President, or, in his absence, the Vice-President, of the Union shall sign checks against the account.

(19) The Executive Secretary shall be responsible to the General Secretary and, with the assistance of such clerical help as is necessary, shall perform all executive and other duties as indicated by the General Secretary.

(20) One copy of each issue of (a) the Transactions, (b) any published List of Members and Officers, and (c) any other publication which may be approved for free distribution to the membership by the Executive Committee of the Union, shall be sent to each Member, Associate, and Corporation Member whose annual dues for the calendar year have been paid by July 1; any person or organization newly elected as Member, Associate, or Corporation Member shall be sent without charge one copy of each of these publications beginning with the calendar year in which elected and for which dues have been paid. Each member on a retired basis, Member ex officio, and Corresponding Member shall be accorded this privilege also.

Each person and organization in good standing in any class of membership may purchase any available publication of the Union at one-third discount from printed price-list to non-members. The General Secretary is authorized to establish discounts for sales of publications in quantity.

ANNOUNCEMENT BY EDITORIAL AND PUBLICATION COMMITTEE

With this Part I of Volume 26 for 1945, publication of the Transactions of the American Geophysical Union is to be made bimonthly--three Parts during 1945 and six Parts annually thereafter beginning with Volume 27 for 1946 to appear in February, April, June, August, October, and December. In general, the Transactions since 1920 (Volume 1) have been issued annually in one or more Parts through 1944 (Volume 25). The development of the scientific aspects of Geophysics has been rapid, particularly so during the past ten years. The Executive Committee of the Union has long planned to meet these growing needs through publication of the Transactions at regular intervals each year. This ambition is now being realized through the great increase in membership--from about 50 in 1920 to over 2,500 in 1945 with Members in every State of the United States and many in Canada and other countries of the Western Hemisphere. The publications of the Union have been made possible by financial support of the National Research Council of the National Academy of Sciences in the earlier years and by annual contributions from the membership beginning in 1932 and the active voluntary service of Members. In 1944 the Rockefeller Foundation, recognizing the importance of Geophysics both nationally and internationally and of the pioneer work done by the Union, generously made a total grant of $20,000 for 1944-47 to supplement voluntary contributions by Members of a special fund of $10,000. With this fund, in addition to the regular annual contributions, it has been possible to provide for full-time services of a small staff including an Executive Secretary, to take over from voluntary services of Members a major part of the responsibilities concerned in publication and the appropriate development of the increasing needs of our profession.

The new form of the Transactions will provide, it is hoped, an improved service to Geophysics generally. The responsibility of publication rests in the Union's Editorial and Publication Committee. That Committee is composed of a Chairman, a Secretary, and Co-Editors from each of the eight Sections of the Union. Each Co-Editor is responsible for papers, abstracts and reviews, bibliography, and notes and news-items concerned with scientific progress and activities within the field of his Section. With the authority of the Executive Committee of the Union, the Editorial and Publication Committee has set up rules governing the quality and kind of material acceptable for publication, which will insure publication of first-order importance. To that end the Committee has prepared and distributed a circular of "Suggestions to authors on preparation of manuscripts for publication in the Transactions of the American Geophysical Union." That circular is reprinted on pages 179-182 in order to make complete record of the Committee's aims and purposes, as well as its ambition to make for superior service of the Transactions to progress of the geophysical fields of science.

From perusal of this Part of Volume 26 notable changes over previous Transactions will be evident, including the classification of material into departments, papers and reports bearing upon the work of all Sections, letters to editor, current news-items and related matters, and activities of the Union and of its Sections and Committees. The goal thus attained in this issue is the result of a long-time dream of the far-seeing Members of the Union. But we are still in the evolutionary process--may it never end! It will be noted that the Editors have given considerable space in this issue to activities of the Union in minutes of meetings and progress-reports of the Union, of its Sections, and of its many Standing and Special Committees. This is deemed desirable in order that our Members and Associates, as well as friends of Geophysics not yet on our rolls--all so widely scattered throughout our country--may be fully informed on all matters pertaining to the Union's plans, policies, and progress. Thus they will be in a position to submit comments as regards our growth and service to Geophysics. Opinions as to how detailed the publication of such minutes and progress-reports should be will be a welcome aid to the Committee in future publication. Suggestions, comments, and constructive criticisms with regard to this first issue--and subsequent ones--are most earnestly invited.

It will be noted that in Part I we have not fully conformed to some of the "suggestions." This is because some of the master-copy was prepared prior to the Committee's final decisions. As time goes on we shall expect an increasing measure of conformance by authors. The chief sin in this regard in this issue is with reference to abstracts, by the authors, at the beginning of each paper. It is to be noted also that the bibliographies are meant only to list the more important current publications.

When preparing a paper for publication, the Editor is in a middle ground between the author and the reader. The easiest thing would be to publish the author's material just as received. It is important, however, that the reader should not be distracted by inconsistencies and errors in composition. A recent note by the Editor of Scientific Monthly [v.   , p. 404, 1945] has put this matter admirably thus: "The editor acting as the first discriminating reader, undertakes to edit the manuscript so that subsequent readers will not hesitate over passages that seemed questionable to him." Paraphrasing further, the Editor tries to do a number of things at once, for example, to make spelling conform with Webster, to make punctuation conform with accepted conventions (in our case generally those of the "Manual of style" published by the University of Chicago Press), and to make the thought read smoothly. We must expect in our annual volumes some 200 or more contributors and perhaps nearly as many conventions of punctuation, styles of English, types of abbreviation, kinds of tabulation, characters of illustrations, details of lettering, etc. In all these the prospective authors will conserve the time of our Co-Editors and the expense of publication by endeavoring to conform to our circular of suggestions.

It is hoped that each Member and Associate of our Union will submit, from time to time as opportunity permits, manuscripts, bibliographical references, and current news-items of interest to his colleagues in Geophysics and thus make the Transactions an ever-increasing medium of interchange and advancement in our fields. Finally, may we count upon your forbearance and criticism--as author and reader--to the end that the Transactions may meet our present expectations and future opportunity.

All communications relating to the Committee's work should be addressed to the Executive Secretary, 5241 Broad Branch Road, Northwest, Washington 15, D. C. The Secretary will see that matter relating to the fields of the several Co-Editors will be appropriately transmitted and considered. At present, the Chairman, Secretary, and Co-Editors representing the Sections of the Union are as follows:

J. A. Fleming, Chairman

Waldo E. Smith, Secretary (ex officio)

C. A Whitten (Geodesy)
Joseph B. Kincer (Meteorology)
Charles J. Fish (Oceanography)
T. P. Thayer (Volcanology)
Earl Ingerson (Tectonophysics)

Frank Neumann (Seismology)
A. G. McNish (Terrestrial Magnetism and Electricity)
W. B. Langbein }
Walter T. Wilson } (Hydrology)

National Research Council
AMERICAN GEOPHYSICAL UNION
5241 Broad Branch Road, N. W.
Washington 15, D. C.

April 16, 1945

SUGGESTIONS TO AUTHORS ON PREPARATION OF MANUSCRIPTS FOR PUBLICATION IN THE TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION

General

The American Geophysical Union welcomes papers and discussions on the various geophysical subjects for publication from members and non-members alike. It reserves the right, however, to reject either papers or discussions in whole or in part and in all cases these are to be edited by the Editorial and Publication Committee. Manuscripts should be transmitted in triplicate to the General Secretary, American Geophysical Union, 5241 Broad Branch Road, N. W., Washington 15, D. C.

It is the responsibility of each author to prepare his material in logical and attractive form, so that it may be read by a specialist in the particular field without need of interpolating the author's intention. To this end, the suggestions below are made. Reasonable compliance by authors will be expected. Because of limitation of funds for purposes of publication, the right is reserved to limit the amount of space assigned to any paper or to ask the author to pay for that part of the cost of printing which may be in excess of the average number of Transaction pages (4 to 6 Transaction pages, or from 10 to 15 double-spaced typed pages).

In view of the necessity for economy, reports and papers should be as concise as possible and historical summaries of previous results and comments that do not lead to definite conclusions should be brief. The amount of detail included should be governed by the importance of the results and of their interest to geophysicists.

The Transactions include several departments, as follows:

(1) Scientific and technical papers relating to the various aspects of geophysics
(2) Discussions of papers under (1)
(3) Progress-reports in the various fields of geophysics
(4) Letters to Editor
(5) Reviews and Abstracts; Bibliography of current publications
(6) Notes (of geophysical interest) and Personalia (obituaries, changes of activity of members, errata)
(7) Union, Section, and Committee Activities

The Union will not be responsible for statements made or conclusions drawn by contributors.

All matters for (1) should have a definite scientific or technical interest and should develop aspects of the geophysical sciences. Matter for (2) may be submitted for publication within a limiting date set by the General Secretary. Items of temporary interest will ordinarily not appear in (1) but in (3 or 4).

Authors should bear in mind that papers prepared for oral presentation are frequently not in form for publication and vice versa. Copy submitted for publication, therefore, should definitely have that form of presentation.

Method of publication--The Transactions are published by the planographic (off-set) method. The master-copy required by this method is prepared from the author's manuscript in the Union's office and a carbon copy is forwarded to the author for careful reading and correction, bearing in mind that corrections and absolutely necessary changes are permissible only when they may be made in same length of line or paragraphs. The typography and page-size are the same as those used in these "Suggestions". The cost of corrections and changes which require extensive retyping of master-copy will be charged against the author. The typing is done on sheets 10-1/2 by 16 inches which are reduced to the size of the Transactions (6-3/4 by 9-3/4 inches overall, the printed matter being about 5-1/2 by 8-3/8 inches on each page).

Preparation of manuscripts

Titles--Titles of papers should be as short as possible--preferably so that they may be printed in one or two lines.

Text--All manuscripts should be in English and should be double-spaced or triple-spaced, typed on one side of the paper only, with wide margins. One original typewritten copy and two carbon copies should be supplied. Papers under (1) must be prefaced by a brief abstract presenting the purpose of the paper, a digest of its contents, and a summary or concise statement of conclusions. Papers will generally not be accepted that contain matter found readily elsewhere. Papers will not be accepted that advocate personal interests. On the other hand, however, a liberal attitude will be taken with regard to acceptance of papers concerning controversial matters or papers which attempt to establish some new thought--even though apparently counter to commonly accepted views--as long as the logic is sound and clear, and the fact that there is controversy is stated. But papers that are just a re-working of previous work, unless they present some new aspect, will not be acceptable under (1). As a general rule, papers will be open for discussion under (2) in the succeeding issues of the Transactions, up to a closure date to be announced in each case. Authors who desire to present closing discussions will be given reasonable time to do so.

Subtitles or subheadings should be used in papers; some of these may necessarily need to be rearranged by the editors.

Manuscripts have been found often with incomplete sentences and other omissions indicating that the authors have failed to check the typed copy. Careful revision by the author before submission of manuscript saves delay and makes for economy in publication.

Remember that brevity is an asset.

Symbols and arrangement of formulas--Special care must be taken to insure correctness of all formulas. Except where sanctioned by standard conventions or usage, Greek letters, unusual symbols, symbols with rules over them, and cumbersome fractions should be avoided. All Greek letters, mathematical signs, and unusual symbols should be clearly and legibly indicated. Show division by solidus when possible; for example (a/b) and not $\frac{a}{b}$, $(a+b)/2$ and not $\frac{a+b}{2}$. When possible, formulas should be written in one line; this, in general, can be readily done and simplifies preparation of master-copy. Except where repetition of data serves a distinct purpose, they should be presented only once; authors often present data two or three times, for example, once in text, once in tables, and once in the illustrations. It is suggested that authors examine recent issues of the Transactions and endeavor to conform as closely as possible to the adopted conventions and style, both of text and illustrations.

Abbreviations--Omit periods after frequently used abbreviations, for example, cm, mm, kv, lb, °C, pct, Ag, Pb, $\log_e$, cfs, etc. Abbreviations for journals follow, in general, the system adopted by the International Catalog of Scientific Literature.

Tabulations--Reference by number to all tables should be made in text. Eliminate extended descriptions in table and box-headings. Carefully check all entries in each table. Supply a concise, descriptive title for each table. Indicate unit used at head of each column. Above all make certain that box-headings for tables are self-explanatory and when such headings cannot be made concise add an appropriate footnote to the table; it is important that a reader may be able to read a table without doubt as to the meaning of the entries. While the time of preparation of a page of master-copy for tabular matter may be several times that for a straight page of text, tables frequently can replace pages of text, and with greater clarity.

References and footnotes--All references to other papers must be complete and must be checked to avoid loss of the editor's time in completing details of references. Each reference must include: Name of the author; title of paper; publication or journal; number of volume; inclusive pages covered by the reference; and year of publication. Example: John Doe, Soil-temperature gradients, J. Agric. Sci., v. 17, pp. 222-238, 1927.

Acknowledgments--Acknowledgments deemed necessary for assistance given in the work reported should be made in a brief closing paragraph.

Illustrations

General--Bear in mind that illustrations overloaded with lettering and unnecessary detail tend to confuse the reader; therefore exercise care to simplify all illustrations for clarity in bringing out essential results and features. It will be found helpful to examine recent issues of the Transactions in this as well as other regards. Reference in text should be made by number to all illustrations used.

Drawings and diagrams--Drawings, diagrams, or other illustrative material should be prepared in black India ink either on white paper or tracing cloth and must be of size such that they will reduce to the limits of the copy-page referred to above and still be legible. To insure the most satisfactory reproduction, the space occupied by the drawing and title of any illustration, as submitted for publication, should not exceed 12 by 8-1/2 inches--limits of single page of master-copy. In special cases, use multiples of single page-size of master-copy, for example, maps, 12 by 17 inches, 24 by 8-1/2 inches, 24 by 17 inches. In order that all pertinent lines and letters may be legible, size and thickness of lettering and thickness of lines must be proportioned according to required reduction for printed page. On the other hand, drawings and diagrams, including graphs, must not be so small that enlargements are necessary. All drawings should be submitted in black and white and preferably the originals should be supplied. Blue-line drawings, blue-prints, and other prints of similar nature will not reproduce satisfactorily and cannot be accepted unless the author pays for redrafting. If coordinate paper is used the coordinates should be blue (not red, orange, or black) with those coordinates to appear in printed copy drawn in India ink.

Lettering should be of such size that after reduction the smallest one will not be less than one mm (one twenty-fifth inch). Do not letter illustrations with a typewriter. Letters and legends may be indicated in pencil and will be inked by the Union's draftsman. Network of rulings, such as cross-hatching, must not be too closely spaced or the reduction will not be satisfactory. For this reason graphs on the original cross-section paper are usually not satisfactory if they must be reduced, unless rulings are in blue, as previously outlined. Generally, tracings should be supplied omitting some of the lines according to the reduction. A rough idea of how well a diagram will stand reduction may quickly be obtained by placing it in a vertical position and then backing off until it measures, on a ruler held at about 15 inches from the eyes, the size to which it is to be reduced. Furthermore, all drawings, including maps, should be compact in their arrangement so as to make maximum use of the available space without confusion. Maps should be prepared in the simplest outline form that will show the essential information. Maps and all other illustrations should be submitted in black and white only, as colors and tinting can be reproduced by the planographic process only at considerably increased cost.

A graphical scale must be provided for maps and other figures requiring scales rather than "Scale 1/4 inch = 1 foot", "1:3,000,000", etc.

Photographic prints--Photographic prints which in the offset-method require screens for reproduction, increase the cost of each page containing them; therefore the number of photographic prints for illustrations should be a minimum consistent with clear presentation. Photographic prints should be carefully selected for contrast and printed on glossy paper and enlarged so that none is less than six, or greater than eight, inches in one dimension. If enlargements cannot be supplied the negatives should accompany the manuscript. In considering the details which will be visible on the screened print remember that the screen will eliminate many small details which appear clearly on the negative. Small-size lettering is particularly subject to such loss and becomes illegible.

Use only a soft-grade pencil when writing identification or title on back of a print; do not type on the front or back of a photographic print; be careful in the use of paper clips so that the edges will not be marred; do not mount prints on heavy paper; do not crease or fold prints; prints and copy for other illustrations should be sent flat protected by heavy cardboard or, for larger copy, in rolls in cardboard tubes.

Note: Photographic prints of line-drawings do not require screening.

Titles--A brief descriptive title must accompany each illustration and a separate list of titles with name of author and figure numbers to provide identification should be supplied. The top of any illustration, when there may be uncertainty as regards orientation, should be marked "top".

Return of copy for illustrations--All illustrative material, including any negatives supplied to, or prepared by, the Union, will be returned to authors if request accompanies manuscript; otherwise all will be destroyed upon publication of Transactions in which they are printed.

Reprints

Reprints will be furnished in accordance with schedule of prices that will be sent with carbon of master-copy for correction. Orders accompanied by remittance in full will be sent post or express paid; otherwise cost of forwarding will be added to cost of reprints.

Aids in preparation of manuscript

Style-manual--In general the editors will adopt the well-established conventions of the University of Chicago Press in "A manual of style" now in its tenth edition. Every effort will be made, however, to preserve the author's style, bearing in mind that it is essential, in any serial publication, that papers by various authors conform to certain adopted conventions.

The preparation of concise, rather than extended, accounts of work of the character covered by our Union requires unusual care and revision. The following texts contain many helpful suggestions:

Suggestions to authors, by G. M. Wood and B. H. Lane, published by Government Printing Office (new edition in preparation).
Preparation of scientific and technical papers, by S. F. Trelease and E. S. Yule, Williams and Wilkins Company, 3d Edition, 1935.
Notes on the composition of scientific papers, by T. Clifford Allbutt, Macmillan and Company, Limited, 1923.

Editorial and Publication Committee,
AMERICAN GEOPHYSICAL UNION

To promote the study of problems concerned with
the figure and physics of the Earth, to initiate and
coordinate researches which depend upon international and national cooperation, and to provide
for their scientific discussion and publication

UNSELFISH COOPERATION IN RESEARCH

TRANSACTIONS
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F. A. VENING MEINESZ--A GEODESIST'S CONTRIBUTION TO GEOSCIENCE

R. M. Field

(This paper is one of a series of essays which will be published under the auspices of the Government of the Netherlands. In this, Dr. FIELD has pointed out some of the broader aspects of the work of a world-renowned geodesist. While this paper was presented before the Section of Geodesy, it has interest for those in other fields of Geophysics as well, perhaps most notably in Tectonophysics.--Editor)

No history of science and scientists in the Netherlands East Indies would be complete without an account of the explorations of VENING MEINESZ with the splendid cooperation of the Netherlands Navy.

Among scientists VENING MEINESZ is classified as a geodesist. He was born at 's-Gravenhage (The Hague) on July 30, 1887, as the son of S. A. VENING MEINESZ, Burgomaster of Rotterdam, and later of Amsterdam. He attended the "Hoogere Burgerschool" and afterwards the Technical College at Delft, from which he graduated in 1910 as a civil engineer. In 1915 he obtained the degree of Doctor of Science from the University of Utrecht, where in 1927 he was appointed Professor of Geodesy. In 1937 he became chairman of his Government's Committee for Geodesy. In 1933 he had been elected President of the Association of Geodesy of the International Union of Geodesy and Geophysics.

VENING MEINESZ' national and international honors need not be listed in this paper, but his accomplishments should be briefed as an outstanding illustration of scientific imagination and method in the exploration of a fundamental physical phenomenon of the Earth. The geographical counterparts of the Netherlands East Indies exist in such other archipelagoes as the West Indies and the Aleutian Islands. Due to VENING MEINESZ' geophysical and geological researches in the Netherlands East Indies we now know that their geographical and structural counterparts have probably reoccurred as great dynamic deformational rhythms of the lithosphere during the entire 1,500,000,000 or more years of our planet's geological history.

It has already been stated that VENING MEINESZ is by training and occupation a geodesist; a scientist who is primarily concerned with methods for determining the mass, weight, density, shape, and surface configuration of the earth--including such inequalities in relief as ocean basins, ocean deeps, continents, and mountains. Primarily, however, a geodesist is an advanced type of surveyor or topographic engineer whose chief responsibility is to improve and perfect surveying instruments and methods. Had VENING MEINESZ confined his activities to the arts and practice of geodesy alone he would still be rated as one of the outstanding geoscientists of today. The story of how he so effectively transgressed the border lines of scientific departmentalism to the great benefit of geoscience is particularly significant as an illustration of his skill in national and international cooperative research and of his appreciation of the natural exploratory advantages of the sovereign territory of the Netherlands.

VENING MEINESZ' principal responsibility to his country was to determine local deflections of the vertical, or the deviation of the plumb-bob, in order to correct certain irregularities in the triangulation survey of Holland. A triangulation-survey may be defined as the most precise method for the determination of geographic positions, or the location of first-order bench-marks to which all local surveys are "tied in," or related.

VENING MEINESZ' great contribution to geoscience was his discovery of the linear belt or strip of negative-gravity anomalies, that is deficiency of density, topographically expressed by the islands and oceanward troughs or foredeeps of the East Indian Archipelago. The outstanding characteristic of VENING MEINESZ, like that of all great scientists, is his interest in anomalies, or those observations which do not seem to fit a generally accepted classification of natural phenomena. Thus, instead of attempting to average out anomalies by purely mathematical mechanics, he studies the anomalies as particularly interesting phenomena in themselves.

Some 30 years ago, while **VENING MEINESZ** was initiating the gravity-survey of Holland, he encountered serious difficulty in the instability of the waterlogged terrain. The standard pendulum-machine which he was using to determine gravity was so jarred by the movements in the ground that he was forced to design an apparatus that would enable gravity to be determined in spite of these disturbances. By swinging two pendulums, instead of one, in the same plane for each observation, he discovered that he could compensate for the vibrational errors of a single pendulum. Thus, in the performance of his geodetic responsibilities, he produced a multiple-pendulum apparatus. **VENING MEINESZ** immediately appreciated the great significance of this geophysical as well as geodetical instrument. Like his colleague and close friend the great American geodesist, **WILLIAM BOWIE** of the United States Coast and Geodetic Survey, **VENING MEINESZ** was fully familiar with the geological implications of isostasy as originally defined by **C. E. DUTTON** in 1889, for the theory of gravitational balance between relatively broad, contiguous areas of different average altitudes, or of topographic relief. According to this theory continents are assumed to "stand high" relative to the ocean basins, because they are composed of lighter and less dense material. The condition of compensation, or no strain, is assumed to exist at some 30 miles below the surface of the Earth, as at this depth all material must be non-rigid and capable of "flow." Hence the definition of isostasy, or the suggestion that the rigid blocks of the crust of the Earth "float" in a uniform sub-crustal medium. According to isostasy the ocean basins are relatively low because the sub-oceanic lithosphere is relatively heavier (more dense) than the continents which are high because they are relatively lighter (less dense). The English Geodesist **PRATT** had demonstrated in his pendulum-survey of India that the Himalayas were high because they were deficient in mass; and the Americans, **HAYFORD** and **BOWIE**, had published monographs on the geological, as well as the geophysical significance, of isostasy. As early as 1875 attempts had been made to determine the density of the sub-oceanic lithosphere by means of a gravity-barometer, and in 1911 **L. A. BAUER** urged the development of an apparatus which would measure gravity at sea with the same degree of accuracy as on the terra firma of the continents.

Deficiency or excess in mass in any portion of the Earth's crust is defined as a gravity-anomaly, and if the theoretical value for gravity, at any position, has been corrected for the topography and for isostatic compensation of the topographic features and compared with the measured value, the difference or anomaly is called an isostatic anomaly. Thus isostatic anomalies signify instrumentally determined deficiency, or excess, of mass of the crust of the Earth in the immediate neighborhood of the gravity-measuring machine.

VENING MEINESZ' first experiment with his multiple-pendulum apparatus was made on a small steamer on the North Sea Canal near Amsterdam. This and subsequent experiments on larger ocean-going vessels suggested that his machine could measure gravity at sea provided certain improvements were made in the mechanism such as photographic recording, gimbal-mounts and such gadgets as would tend to reduce the effect of the motion of the ship. However, he eventually discovered that the mechanical vibrations of a steam driven vessel seriously interfered with the accuracy of his instrument. It was then that he conceived the idea of using a submarine, not only because of the possibility of obtaining greater stability beneath the surface but primarily because submarines, when operating below the surface, are driven by electric motors with a minimum, if not complete absence, of mechanical vibration. **VENING MEINESZ** therefore consulted the Netherlands Admiralty, and especially those officers who were particularly skilled in the operations of submarines. The purely scientific character of the problem so appealed to these naval officers that they gave full cooperation and thus helped to set a standard of naval cooperation in marine geophysics which was later followed by the American, British, French, Italian, Russian, and Japanese navies.

In preparing for his first extensive submarine gravity-measuring expedition **VENING MEINESZ** wisely selected the outer arc of the East Indies as affording the greatest difference in altitudes (exclusive of sea-level) between the tops of the mountainous islands and the contiguous foredeeps or troughs on the oceanward side of the archipelago, since these troughs were already known to be much deeper than the general level of the ocean bottom. By selecting such a geographical area for the first test of his machine he was reasonably sure that any slight inaccuracy in its operation would probably be more than compensated by the maximum difference in topography (relief) of his gravity-measuring traverse. In this respect he was entirely correct, but the gravity-anomalies which he obtained were certainly not what he had expected!

The first expedition was on the Netherlands Submarine K II in 1923; the second expedition, on the Netherlands Submarine K XI in 1925; the third expedition on the Netherlands Submarine K XIII in 1926; the fourth expedition on the same Submarine in 1927. In the first expedition, **VENING MEINESZ** used the same Strukrath apparatus, of four bronze pendulums swinging in two planes,

that he had used in his preliminary experiments on the North Sea Canal. During the later three expeditions he used a three-pendulum apparatus, and perfected such improvements as photographic recording of each pendulum separately, multiple-chronometer readings in the timing of the pendulums, better gimbal-suspension, better pendulum-bearings to decrease friction, and other details in design which not only increased the accuracy of the entire apparatus but also its ease of operation. Between 1923 and 1927 after much hard labor, and with the full cooperation of the Netherlands Navy, VENING MEINESZ had definitely proved the accuracy of what we may now designate the VENING MEINESZ Marine Gravimeter; but, this assurance of the dependability of his apparatus made the gravity-anomalies which he had obtained all the more astounding. He discovered greater gravity-anomalies, regardless of sign, than had hitherto been found for any part of the Earth's crust, or lithosphere. More astonishing still this relatively narrow line of anomalies, closely following the foredeeps or troughs on the oceanward side of the great sinuous island archipelago, proved to be a well-defined strip of negative anomalies! As VENING MEINESZ had expected, the general gravity-field of the sub-oceanic lithosphere was slightly plus, intimating a greater density than that of the continents. Why, therefore did these great foredeeps which occurred as major depressions in the sub-oceanic lithosphere register a greater deficiency in density than the highest mountains on the continents? Could it be that this astounding negative-anomaly strip which we now refer to as the VENING MEINESZ Strip, was a direct refutation, in such oceanic regions, of the great principle of isostasy? Thus by 1927 VENING MEINESZ had discovered one of the apparently greatest anomalies in the whole of geoscience, but an extremely

**Fig. 1--F. A. Vening Meinesz, Washington, D. C., 1928
(Photo courtesy Underwood and Underwood)**

dynamic anomaly which, like geomagnetism, makes no direct and measurable impression on our senses, but is as fully important in geoscience as earthquakes and volcanoes whose superficial phenomena we now suspect may be closely related, in origin, with his discovery of the negative-anomaly strip in the Netherlands East Indies.

WILLIAM BOWIE had followed the discoveries of VENING MEINESZ with increasing interest. Although the leading authority of the geophysical implications of isostasy, he was neither disturbed nor dismayed at what, at first, appeared to be a serious blow to isostasy. Anxious as always to expand gravity-surveys, both on land and at sea, BOWIE urged the collaboration of the United States Navy with VENING MEINESZ for the geophysical exploration of the Gulf of Mexico and those portions of the Caribbean Sea which were internationally open waters. BOWIE aroused the interest of Captain C. S. FREEMAN, Superintendent of the United States Naval Observatory, and eventually VENING MEINESZ was invited to continue his explorations in the Gulf-Caribbean Region with the further encouragement and cooperation of the National Academy of Science and the Carnegie Institution of Washington. This expedition was made during the fall of 1928 with the United States Submarine S-21. VENING MEINESZ was accompanied by F. E. WRIGHT of the Carnegie Institution of Washington, and E. B. COLLINS of the Hydrographic Office of the United States Navy. This expedition produced some noteworthy results, such as: (1) The suggestion that the Mississippi Delta is in isostatic equilibrium; (2) deficiency in gravity parallels the submerged margin of the continental shelf. However, the plan of the expedition seems to have been rather to test certain suboceanic areas as to the theory of isostasy rather than to determine whether or not the West Indian Archipelago was geophysically as well as geographically a counterpart of the East Indian Archipelago. In both the American and the previous Netherlands expeditions VENING MEINESZ had the advantage of the recently perfected sonic-sounding method for determining sub-oceanic topography, although full use of this rapid and accurate technique, so essential in the computation of gravity-anomalies, was not fully developed until 1932. In 1929, VENING MEINESZ made another gravity-measuring cruise to the East Indies in the Netherlands Submarine K XIII, and marine gravimetry had now become a "fashionable" adjunct to oceanographic exploration.

The Russian Navy made a gravity-survey of the Black Sea in 1930 and the Italian Navy a gravity-survey of the Mediterranean in 1931. Also, in 1931, gravity-determinations were made with the VENING MEINESZ apparatus in the Arctic Ocean during the Nautilus Expedition. It was not until 1932, however, that any serious attempt was made to prove the full geological as well as the geophysical significance of the strip of negative-gravity anomalies associated with the East Indies Archipelago. It had naturally taken several years for the leading structural geologists of the world to begin to appreciate the possible significance of VENING MEINESZ' geophysical discovery as directly related to tectonophysics, or the application of geophysical methods and techniques to exploration and study of mountain building and the accompanying phenomena of volcanoes and earthquakes. During his explorations in the Bahamas(1927), R. M. FIELD had discussed with WILLIAM BOWIE the use of a gravity-survey of the islands to determine whether or not the coral reefs and associated carbonate sediments were underlain by volcanic rocks of greater density. With the cooperation of the United States Coast and Geodetic Survey a gravity-survey was made in the Bahama Region. This survey definitely proved that the Bahama Islands were not extinct volcanoes capped with coral reefs and that their geomorphology could not be explained in that way. It was further proved that the whole Bahama Region was structurally in no way related to the West Indian Archipelago, and it remained to be discovered as to what part Cuba played in the geological history of the Gulf-Caribbean Region. BOWIE then urged a marine gravity-survey in the deep waters between the islands, and VENING MEINESZ consented to make such a survey provided it could be organized with the essential cooperation of either the Netherlands, British, or American Navies. In December, 1932, VENING MEINESZ attended the annual meeting of the Geological Society of America held in Tulsa, Oklahoma. It was at this meeting that he first thoroughly aroused the interest of the leading structural geologists in the United States and, in particular, conferred with B. WILLIS, A. C. LAWSON, W. H. BUCHER, W. T. THOM, and several petroleum geologists who were international pioneers in the development of geophysical-geological techniques. With the cooperation of the British Government, the United States Navy, the United States Coast and Geodetic Survey, the Geological Society of America, the American Geophysical Union, and the Department of Geology, Princeton University, the United States Navy-Princeton Expedition to the West Indies had already been organized. On this expedition VENING MEINESZ had the use of the United States Submarine S-48 and the Submarine Tender Chewink which made the bathymetric soundings with the most modern equipment, so essential to the sub-oceanic gravity-surveys. While VENING MEINESZ was determining the sub-oceanic gravity-anomalies, the gravity-survey on the islands was continued with the cooperation of the United States Coast and Geodetic Survey and several private agencies. VENING MEINESZ was assisted by T. C. BROWN of the United States Naval Research Laboratory, and a young geologist from Princeton, H. H. HESS, who has since become one of the leading authorities on the tectonophysics of island arcs.

Later in the same year VENING MEINESZ made a gravity-survey of the Mid-Atlantic Ridge near the Azores, in the Netherlands Submarine K XIII. M. MATUYAMA made a gravity-survey of the Nippon foredeep with a VENING MEINESZ apparatus on board the Imperial Japanese Submarine RO-57, and P. MARTINI made a gravity-survey of the northeast Mediterranean with a VENING MEINESZ apparatus on board the Italian Submarine Fresnel. In 1934, VENING MEINESZ made a gravity-survey in the Netherlands Submarine K XVIII from Holland to Brazil to Capetown to Australia to Java; MATUYAMA made a gravity-survey of the Japan Deep; and G. CASSINIS in 1935 further explored the Mediterranean, in the Italian Submarine Des Geneys.

In 1936, as Chairman of the Committee on the Geophysical and Geological Study of Ocean Basins of the American Geophysical Union, R. M. FIELD organized the United States Navy-American Geophysical Union Expedition to the West Indies, with the cooperation of the United States Navy, the United States Coast and Geodetic Survey, the Geological Society of America, the American Bell Telephone Laboratories, the Woods Hole Oceanographic Institution, and the American Philosophical Society. HESS was on this expedition as geological expert and M. EWING of Lehigh University was in charge of the gravimetric survey, assisted by R. J. HOSKINSON of the United States Coast and Geodetic Survey. The gravity-cruise was made in the United States Navy Submarine Barracuda. EWING had succeeded in making some further improvements in the VENING MEINESZ apparatus--notably in the mechanical timing of the pendulums. It was this expedition that definitely proved that the West Indian Arc was tectonophysically similar to the East Indian Arc, and that the VENING MEINESZ strip of negative gravity anomalies was one of the greatest phenomena in the deformation of the lithosphere. The theory of isostasy had not been disproved--in fact it had been somewhat strengthened--but a new mechanism had been discovered in mountain building which had introduced an entirely new concept in structural geology. At present the VENING MEINESZ negative gravity-anomaly strip as peculiarly associated with island arcs is interpreted by VENING MEINESZ and P. H. KUENEN (Netherlands), H. H. HESS, W. H. HOBBS, B. WILLIS, W. H. BUCHER, R. A. DALY and R. M. FIELD (U. S. A.), E. B. BAILEY and O. T. JONES (England), L. W. COLLET (Switzerland), and others in the following manner:

(1) A strongly negative gravity-anomaly belt, or strip, coincides with the outer, convex side of island arcs such as the Netherlands East Indies and the West Indies. The width of the negative gravity-anomaly strip is approximately less than 50 km wide. In the East Indies the strip is 8,050 km long, and in the West Indies it is well defined along the entire arc from the eastern end of Cuba to the Coast of South America. The order of magnitude of the gravity-anomalies within the area of the negative strip is from -150 to -200 milligals, and there can be no doubt that the area of the negative gravity-anomaly strip signifies an abnormal, local deficiency in density for the entire thickness of the lithosphere for that area--certainly a local, but exceedingly important departure from isostatic equilibrium.

VENING MEINESZ and his countryman, KUENEN, were the first to recognize the great geological significance of this discovery and, together with HESS, suggested not only the cause of the phenomena in terms of structural geology, but also the consequent relation of volcanic activity and the origin of igneous rocks, including the very significant and concomitant belts of serpentinized peridotite intrusions. Others, notably N. H. HECK, have discussed the significant relation of VENING MEINESZ' discoveries to the phenomena and origin of earthquakes.

The outer crust of the Earth, or lithosphere, is known to have a specific gravity, or density, of approximately 2.7. This lithosphere has been shown by the seismologists to have a thickness of 25-35 km with an underlayer of the same thickness having a specific gravity or density of approximately 3.0. Beneath the layer of density 3.0 occurs a third layer of density 3.3. The outer layer of density 2.7 therefore characterizes the lithosphere to the depth of isostatic compensation. This is frequently, though incorrectly, spoken of as the granitic layer because the mean average chemical composition and density of all types of rocks which compose the lithosphere is approximately that of the chemical composition and density of the igneous rock granite. The immediately underlying couch or stratum of denser material, because of high temperature and pressure, has no rigidity and exists as a magma which, when it finds its way into the lithosphere, cools and solidifies as an igneous rock called basalt. The sub-basaltic layer or couch is composed of an even denser magma (sp. gr. 3.3) which when injected into the lithosphere solidifies to form the ultra-basic igneous rock known as peridotite. It should be particularly noted that the increase in difference in density downward from the granitic to the basaltic to the peridotitic layer is 0.3. VENING MEINESZ and KUENEN, realizing that the thickness of the granitic and the basaltic layers was approximately the same, suggested that within the area of the pronounced negative gravity-anomaly strip the granitic layer had entirely displaced the basaltic layer, thereby becoming 50-70 km thick, or twice the normal thickness of the lithosphere, and that island arcs, such as the East Indies and the West Indies, are long narrow structural belts where the lithosphere is close to, if not in direct contact with, the peridotitic layer. **VENING MEINESZ** further suggests that the peculiarly localized displacement of the basaltic layer by the lithosphere is due to a great compressional downfold of the lithosphere; and **KUENEN** further strengthens this theory by laboratory experiments in which he was careful to adapt the strength of the materials to the scale of his model. Thus was born the concept of the Tectogene, or downfold of the entire lithosphere, which since 1933 has played, and will continue to play, an important part in all observations and theories regarding the structure and origin of mountains.

One hundred and two years ago the **ROGERS** brothers described the structure of the Appalachian Mountains of Pennsylvania as a relatively narrow but thick belt (20,000 feet) of marine and estuarine sedimentary rocks which had been folded, faulted, uplifted, and eroded so as to produce the mountains which we see today.

In 1873, **J. D. DANA** suggested that the thick accumulation of sediments filled a long, narrow trough as it was being formed by lateral compression of the lithosphere. He also suggested that, after the trough had been filled with thousands of feet of sediments, its further compression squeezed the sedimentary filling into the great series of folds whose uplifted and eroded remnants form the present ridges and valleys of Pennsylvania. Such great compressional troughs he called geosynclines, and the folded filling of the troughs, synclinoria. The geosynclinal theory, originating from the study of the Appalachian Mountains, has been found to be applicable to the North West Highlands of Scotland, to the Swiss Alps, and to other regions where the stratigraphy and structure of the deformed rocks had been sufficiently studied. The geophysical studies in the Netherlands East Indies and the consequent leadership of **VENING MEINESZ** in the geophysical study of the West Indies suggests that the foredeeps in front of these great island arcs represent geosynclines in the making, but these geosynclines were not filled with sediments because of the lack of source material from the narrow bordering strip of islands (geanticline). Thus, the great curved linear geosynclinal belt, or anticlynoria of the Carpathians, Alps, and Apennines is remarkably similar in origin to the embryonic development of the present-day island arcs. **VENING MEINESZ** and **KUENEN** have suggested the Tectogene, as the father of geosynclines, and their accompanying thick belts of deformed eroded sedimentary rocks and igneous intrusions.

A few of the most significant branches of geoscience which are particularly affected by the first discovery of the negative-anomaly strip in the East Indian Archipelago are:

(1) Theory and origin of geosynclines
(2) Location and origin of earthquakes
(3) Origin of volcanoes
(4) Origin of ultra-basic eruptives and serpentines
(5) Direction and rate of migration of geographic coordinates
(6) Depth of isostatic compensation
(7) Permanency of ocean basins
(8) Numerous problems in stratigraphy and structural geology
(9) Origin and distribution of geomagnetism

Such has been the scientific contribution of Holland, through **VENING MEINESZ** and the Netherlands East Indies, to the whole of geoscience.

In their introduction to "The contribution of Holland to the sciences" (1943), **A. J. BARNOUW** and **B. LANDHEER** make the following observations: "The history of his own special field of knowledge is a field to which few scientists pay attention . . .In times like ours it is of significance to see how the combined efforts of many people have led to the discoveries or innovations which we so easily ascribe to one person. . . . That the Netherlands has always pursued a policy of tolerance has been an essential factor in the development of its scientific achievements." We have tried to emphasize the effect which **VENING MEINESZ**, the Netherlander, has had on geoscience. What has been the effect of geoscience on **VENING MEINESZ**, the Netherlander?

The last time that **VENING MEINESZ** was able to mix freely with his international colleagues was in September, 1939, during the Seventh General Assembly of the International Union of Geodesy and Geophysics in Washington, D. C. For several weeks, previous to this Assembly, events in Western Europe had rapidly become more disturbing. Delegates from most of the adhering countries, then 32 in number and including all of the present belligerents, arrived in fair numbers, but there was some discussion as to the advisability of cancelling the Assembly. Finally, just previous to the meeting, Germany invaded Poland, and there was a hurried meeting of the Bureau of the Union which determined to carry on. In this discussion the Bureau was greatly encouraged by the United States Department of State, whose Secretary, CORDELL HULL, opened the Assembly with these words: "It is my fervent hope, which the people of this country share, that the day may soon come when the statesmen of the world will take a leaf from the book of the scientists and solve international political problems in the same dignified and friendly spirit."

During the succeeding week of the Assembly VENING MEINESZ was a tower of strength. No one foresaw more clearly than he the consequence of Germany's invasion of Poland, yet his tolerance during this international gathering of scientists in Washington was largely responsible for the calm and friendly spirit of its deliberations. As President of the International Association of Geodesy, his were the primary interests of a great specialist whose scientific inclinations were to emphasize the international importance of geodesy. However, his researches in the Netherlands East Indies, extending to all the oceans and continents of the Earth, had taught him the importance of cooperation not only of different specialists, but also of all manner of men. Above all, he had made the most of the full social opportunities of fundamental geoscience, in contradistinction to the somewhat asocial implications of mathematics and astronomy or the economic implications of physics and chemistry. He was particularly trusted by every one--Poles, Germans, Italians, Japanese, and British alike. According to last accounts VENING MEINESZ is still in Holland. We are not informed as to his present physical or mental condition, but we sincerely hope that in the interests of postwar planning he will be able to help us. Any scientist who has accomplished so much in international cooperation without the destructive stimulus of war will be particularly needed during the postwar period of reconstruction. VENING MEINESZ is such a scientist; to his more intimate colleagues he is still a typical Hollander and a famous explorer of the structure and origin of the Netherlands East Indies. His hypothesis of the Tectogene will undoubtedly be modified, and may even be replaced, but his discovery of the negative gravity-anomaly strip will remain as the greatest advance in the application of gravitational physics to geology since the discovery of the deflection of the vertical, and the consequent geophysical-geological concept of isostasy.

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Note by Author, August 20, 1945--The following is a quotation from the letter from VENING MEINESZ to W. D. LAMBERT, dated July 13, 1945: "I myself am in good condition although I have not quite recovered my old strength. We have been mad with joy when at last liberty came to our part of Holland. As everybody else, I lost much weight and have been very tired, but I am recovering quickly now. Since our liberation, I have taken up the directorship of the Meteorologic-Oceanographic-Geophysic Institute at De Bilt."

Princeton University,
Princeton, New Jersey

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(See also pp. 203, 212, 216, 240, 266, 302, 314, 318, 322, 323, and 324)

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Transactions, American Geophysical Union Volume 26, Number II October, 1945

GRAVITY-OBSERVATIONS IN THE MARITIME PROVINCES

George P. Woollard

General statement--In the summer of 1944, 521 gravity-meter stations were established in the Maritime Provinces of Canada. This work was a cooperative venture carried out by the Dominion Observatory and the writer, representing the Special Committee for the Geological and Geophysical Study of Continents of the American Geophysical Union. The instrument used was the X-type gravity-meter on loan to the American Geophysical Union by the Humble Oil Company.

Location of stations--Most of the stations were located in the southern and eastern portions of the Province of New Brunswick and were established by A. H. MILLER of the staff of the Dominion Observatory. In addition to these stations, traverses crossing southern Quebec, New Brunswick, and Nova Scotia were established by the writer assisted by Mr. MILLER. All station locations are indicated on the iso-anomaly maps of New Brunswick and Nova Scotia in Figures 1 and 2.

Survey-control--The instrument was calibrated at Woods Hole, Massachusetts, using constants determined from numerous pendulum gravity-station occupations made on a transcontinental traverse [see 1 of "References" at end of paper]. We then proceeded to Calais, Maine, establishing stations at roughly 15-mile intervals along the way and reoccupying United States Coast and Geodetic Survey pendulum-stations at Rockland and Calais, Maine. Mr. MILLER continued the traverse into Canada reoccupying Dominion Observatory pendulum gravity-stations at St. John and Fredericton, New Brunswick. This traverse not only added to the knowledge of the gravitational field in the eastern seaboard but also tied the pendulum-stations of the United States Coast and Geodetic Survey to those of the Dominion Observatory.

All of the stations were tied to the existing network of pendulum-stations and put on an absolute basis. The pendulum gravity-stations reoccupied were those at Fredericton, St. John, Bathurst, Moncton, Woodstock, Perth, and Edmundston in New Brunswick, Riviere du Loup and Notre Dame du Lac in Quebec, and Truro and Amherst in Nova Scotia.

The station at Fredericton, New Brunswick was selected as the primary base to which all values were referred and ties to this station were made periodically throughout the work. Other pendulum-stations used as secondary bases and reoccupied more than once were those at St. John, Moncton, and Bathurst in New Brunswick and Amherst in Nova Scotia.

A comparison of the observed values of gravitational attraction relative to Fredericton determined with the gravity-meter and with pendulum-apparatus is given in Table 1.

Table 1--Comparative values of gravity-observations

Station	Meter value	Pendulum value
St. John, N. B.	980.6668	980.667
Fredericton, N. B.	980.6900	980.690
Moncton, N. B.	980.7320	980.732
Amherst, N. S.	980.6930	980.693
Bathurst, N. B.	980.8352	980.840
Truro, N. S.	980.6696	980.666
Riviere du Loup, Q.	980.8215	980.822
Notre Dame du Lac, Q.	980.7856	980.787
Edmunston, N. B.	980.7806	980.778
Perth, N. B.	980.7477	980.747
Woodstock, N. B.	980.7036	980.703

Reduction of data--All of the values for stations were reduced for the effect of latitude, elevation, and mass above sea-level so as to obtain simple Bouguer anomalies. In computing the gravitational effect of the topography above sea-level, a mean value of density of 2.67 was used. These anomalies were plotted at their respective station-locations and iso-anomaly contour-maps constructed.

Description of gravitational field--In both Figures 1 and 2 it is seen that the gravitational field is complex and the stations taken were not sufficient to describe adequately the conditions present. This was particularly true in central and northern New Brunswick, the Gaspé Peninsula Region of Quebec and in southern Nova Scotia.

Along the St. Lawrence River there appears to be a deficiency of about 50 milligals in the gravitational field over and above that which can be attributed to latitude, elevation, and topography. In southern New Brunswick, there is an area paralleling the Bay of Fundy where there is an excess of gravitational attraction of about 20 milligals. Similarly there are other marked positive-anomaly areas in southern Nova Scotia and on the Gaspé Peninsula with isolated negative-anomaly areas interspersed between them.

The marked variations in the gravitational field are further emphasized by the two traverses made from the Nova Scotia Coast to the St. Lawrence River shown in Figure 3. On these traverses, following the eastern and western boundaries of New Brunswick, neither the magnitude of the anomalies nor the general pattern is the same.

Correlation with geology--The geologic implications of the gravitational measurements are that they appear to reflect both deep-seated and near-surface lithologic variations. The marked regional low, reaching a maximum in the St. Lawrence Valley, is believed to be a continuation of "Blue Ridge-Hudson Valley" low observed to extend from Virginia into northern New England [2, 3, and 4]. This has been correlated with a down-buckle or down-thrust zone of granitic material into denser substratum. It parallels the strike of the Appalachian Mountain System and occurs mostly beneath the zone of overthrusts along the eastern edge of the Appalachian tectonic province.

Superimposed upon this regional feature are numerous highs and lows believed to reflect for the most part intra-basement lithologic variations. Some of these gravitational features appear to reflect surface geologic formations as in the vicinity of Bathurst. Here, exposed intrusive masses of basic rocks (gabbro to peridotite) with an average specific gravity of about 3.2 are characterized by gravitational highs of 10 to 15 milligals as shown by traverse A-A of Figure 3. Similarly the gravitational high between Riviere du Loup and Edmundton on Traverse B-B of Figure 3, occurs on the axis of an anticline along which there are exposures of dense intrusive rocks.

On the other hand, in the area between Shediac and Amherst, Traverse A-A (Fig. 3), it was found that known salt-domes were characterized by marked gravitational lows. Whether the pronounced gravitational low shown on the profile near Amherst is due to the presence of salt, however, is not actually known.

On the basis of the present observations, it appears that the establishment of additional stations would yield considerable information concerning both deep-seated and near-surface geologic phenomena.

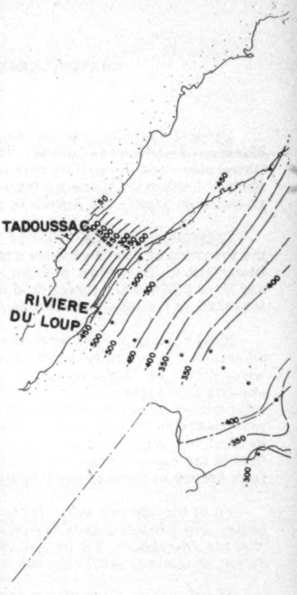
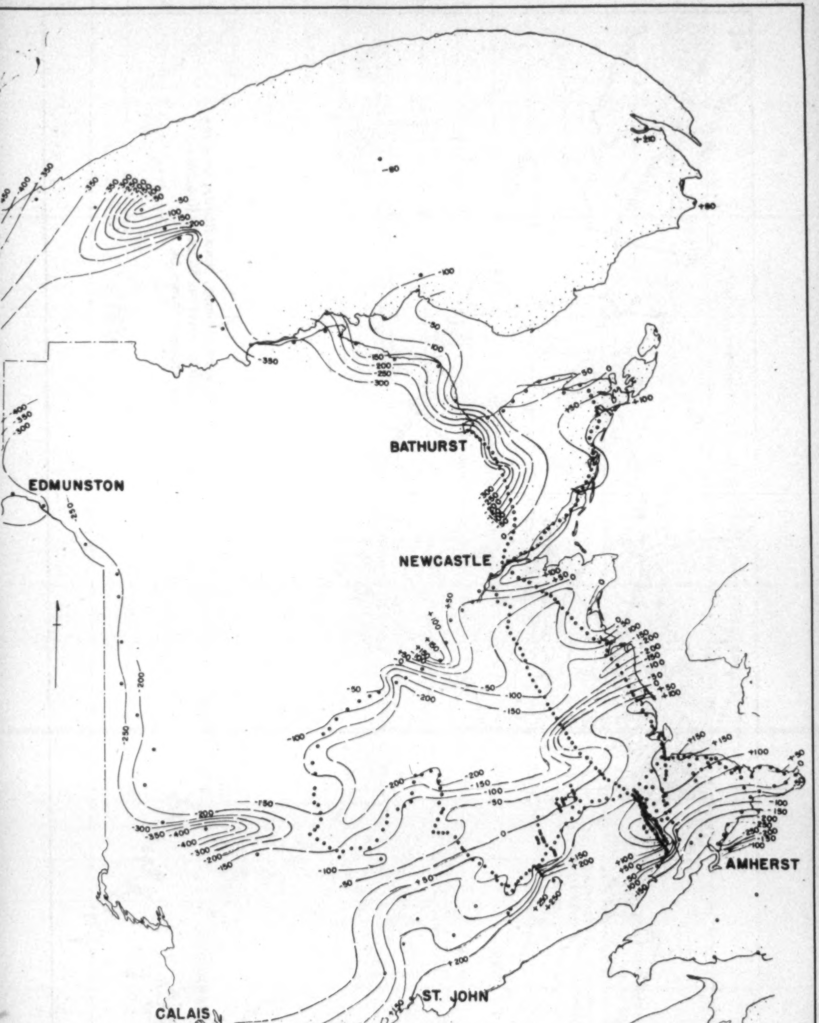


Fig. 1--Gravity-anomaly map, New Brunswick, Bouguer anomalies, contour-interval 50 units (5 mgals); gravity-meter stations shown by •

SCALE
0 MILES 16


EDMUNSTON
BATHURST
NEWCASTLE
ST. JOHN
CALAIS
AMHERST
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-300
-250
-200
-150
-100
-50
0
+50
+100
+150
+200
-400
-80
+80

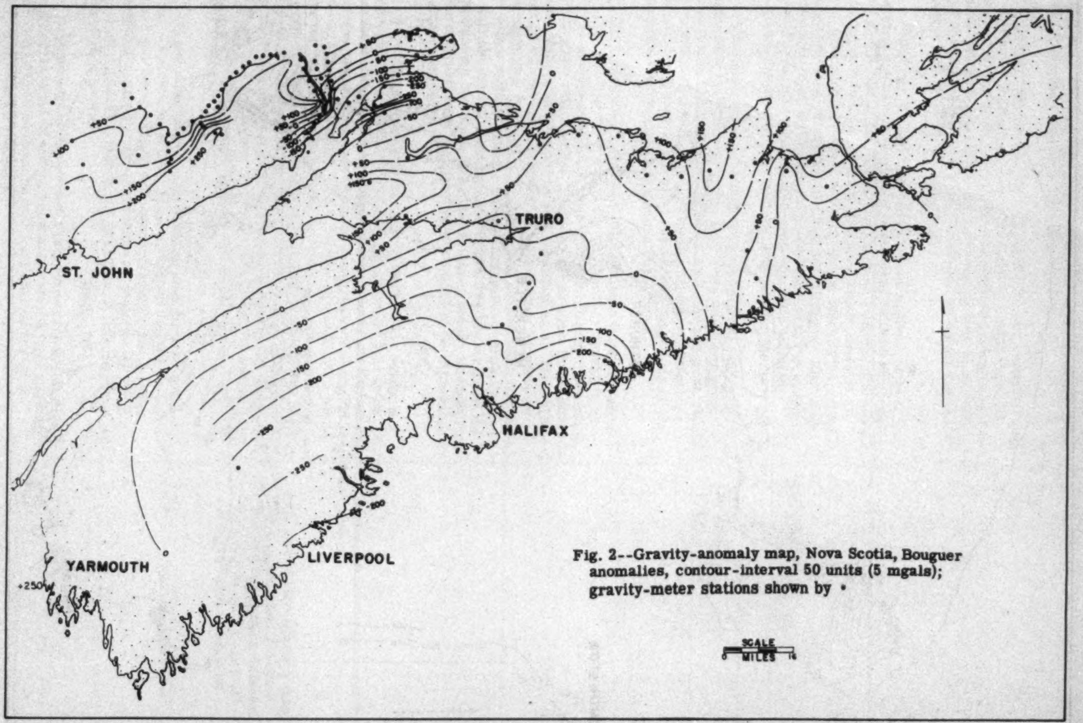
ST. JOHN
TRURO
HALIFAX
YARMOUTH
LIVERPOOL
+250
+50
+100
+150
+200
0
-50
-100
-150
-200
-250
SCALE
MILES
0

Fig. 2--Gravity-anomaly map, Nova Scotia, Bouguer anomalies, contour-interval 50 units (5 mgals); gravity-meter stations shown by •

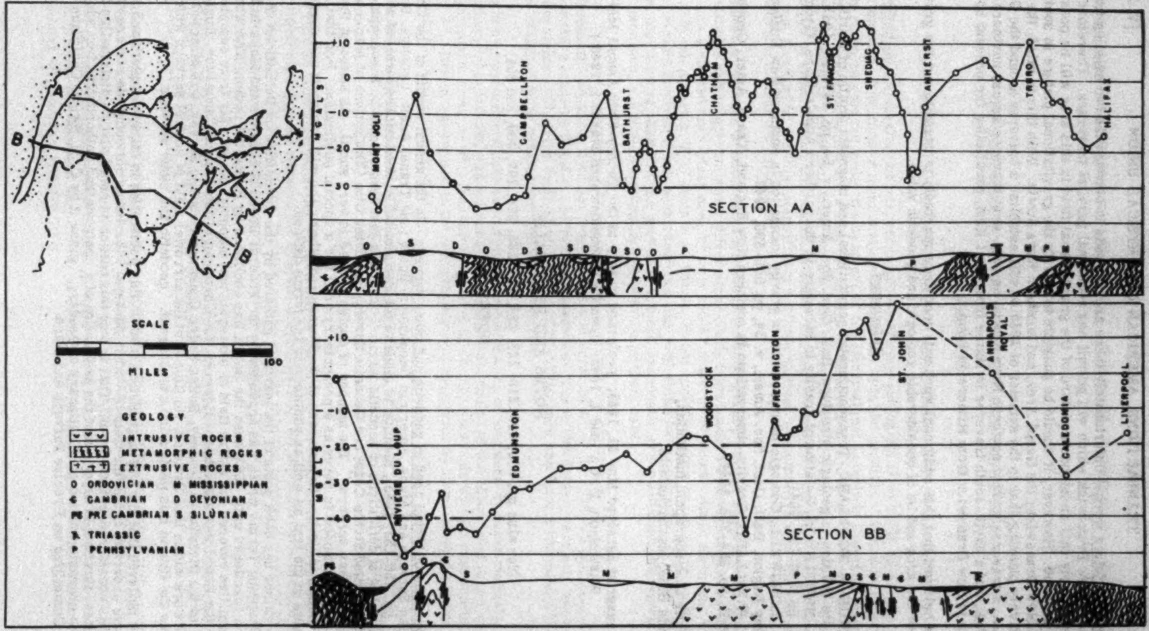

Fig. 3--Gravity-anomaly sections, Maritime Provinces, Bouguer anomalies

Proposed future work--Unfortunately there are no roads in between the two existing traverses in northern New Brunswick which will permit any additional parallel traverses. Therefore it does not appear likely that an adequate picture of the gravitational field in this area will be possible for quite some time. However, it should be possible to clarify the gravitational picture in southern and western New Brunswick, the Gaspé Area, and southern Nova Scotia. With this in mind, the writer is tentatively planning that in the summer of 1945 he will establish a traverse around the Gaspé Peninsula, a traverse around southern Nova Scotia, an east-west traverse across northern New Brunswick, and a north-south traverse in Maine from Fort Kent, paralleling the present north-south traverse in New Brunswick from Riviere du Loup.

It is believed that this additional work will contribute markedly to rounding out the gravitational picture of the area and be of considerable geologic and geodetic value.

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NOTES AND PERSONALIA

(See also pp. 200, 204, 219, 223, 224, 248, 265, 274, 297, 300, and 304)

NOTES

Definitions of terms used in geodetic and other surveys--In the annual report of the Committee on Precise Surveys and Maps, American Geophysical Union (see Trans. Amer. Geophys. Union, v. 26, Pt. I, pp. 150-152, 1945), mention is made of the completion, in preliminary form, of a "comprehensive list of definitions of geodetic terms." This has just been printed by lithographic process, by the United States Coast and Geodetic Survey, under the title "Definitions of terms used in geodetic and other surveys." The number of copies printed is very small. As stated in the introduction, it is "intended to serve as a preliminary draft for a special publication. For that reason its distribution is limited to members of the Bureau and others who will review it and suggest improvements in the text as well as additions to the terms defined."

The author has used some of the material gathered by the Committee on Definitions of Surveying and Mapping Terms which was appointed by the Federal Board of Surveys and Maps in 1938 and which functioned until 1942 when the Board was abolished by Executive Order. The work of that Committee covered the entire field of surveying and mapping, but was far from complete at the time the Board was abolished. However, the Chairman of the defunct Committee, Hugh C. Mitchell of the Division of Geodesy, United States Coast and Geodetic Survey, was directed to continue his work within that Division, limiting it to the narrower field of control surveys which includes, as the title to this publication expresses it, "geodetic and other surveys."

It is believed that the list of geodetic terms in this publication is fairly complete and their definitions accurate, but in the field of "other surveys," the list is not complete nor are all definitions considered in final form. That is why this edition is small and its distribution limited. In due time, this should bring about the publication of a complete and authoritative text which will merit the characterization of "Dictionary of Geodesy," given it by C. H. Swick, Chairman of the Special Committee on Precise Surveys and Maps.

Transactions, American Geophysical Union Volume 26, Number II October, 1945

REDETERMINATIONS OF LATITUDE AND LONGITUDE

Wm. Markowitz

(Communicated by the Superintendent, United States Naval Observatory)

Introduction--A question of interest to geodesists and geologists is whether or not the continents are moving. The answer from modern observation is in the negative. World-longitude operations by radio carried out under the auspices of the International Longitude Commission indicated only shifts in longitude which are within the errors of observation [see 1 of "References" at end of paper]. A similar result was found for the radio operations at Kornok, Greenland [2]. No definite changes in mean latitude are shown by observations made with the zenith-instruments of Washington, Greenwich, and the International Latitude stations when modern star-places and proper motions are used in the reductions.

If, however, we turn to observations made in the last century we find several carefully determined latitudes and longitudes which differ appreciably from modern redeterminations. The apparent motions indicated are: Greenland, 5^s west and 3" south in 60 years; South America, 1^s east in 50 years; North America, 0".7 south in 70 years. From considerations based solely on the internal probable errors involved it has been concluded that real shifts have occurred. It is well known, however, that a set of observations may have a large systematic error although the internal agreement is excellent, and this is especially likely in the present case.

Thus, the 1854 Greenwich-Paris telegraphic longitude determinations [3] were in "remarkably good agreement" whereas the final longitude was in error by $0^s.4$. In 1888 two simultaneous determinations were made by English and French observers. These two series were self-accordant, but differed systematically from each other by $0^s.4$. This difference was later reduced to $0^s.2$, a result also obtained from similar determinations in 1892.

Another important example concerns the determination of longitude by lunar methods, namely culminations, occultations, and eclipses. If the right-ascension of the Moon used in the reductions has a systematic error of $0^s.1$ then the longitudes in all three methods will be systematically in error by 3^s. Hence, agreement in the determination of longitudes by lunar methods is not an indication that the results are reliable.

If the older determinations are to be accepted as they stand it would mean that large shifts occurred until the invention of the telegraph, moderate shifts until the invention of radio, and practically none since then. This is so difficult to believe that it was decided to re-examine the older observations.

The results of this investigation showed that in all cases: (a) Systematic corrections were required which when applied reduced the original discrepancies; (b) the discrepancies are definitely less than the errors of observation, for they are no greater than the systematic errors known to have affected similar observations made elsewhere under more favorable conditions. A summary of the results follows.

Greenland: Longitude--The longitude of Sabine Island, Greenland, was determined in 1870 by BÖRGEN and COPELAND from 17 lunar culminations and four occultations [4]. In 1932 JELSTRUP found a longitude 5^s greater by radio [5].

The longitudes from culminations show the usual systematic effects, a limb-difference due to irradiation and an absolute difference due to personal equation. The mean longitude from limb II is 8^s greater than from limb I and the longitude by COPELAND is 7^s greater than BÖRGEN'S. The observations were not well balanced. If equal weight is given to each limb (the usual practice) and to each observer, then the longitude from culminations is increased by 2^s and the mean longitude becomes 4^s less than JELSTRUP'S.

It has been known for a long time that longitudes derived by lunar methods are affected by large systematic errors [6]. This was shown by internal disagreements, by comparison with chronometric longitudes, and by comparison with telegraphic longitudes made a short time later (North America, 3 years; South America, 12 years).

Table 1 lists the corrections to longitudes determined by lunar methods, mainly culminations, in the period 1850-70, as indicated by modern observations. The corrections for South America would be 1^s larger if referred to the original determinations by cable.

Table 1--Corrections to longitudes determined by lunar methods

Station	Correction in seconds				References
Washington, D. C.	+ 3	+1	+2		[6]
Pacific Coast Stations of the U. S. Coast	+ 3	+3	+6	+2	
and Geodetic Survey		+2	+6	+5	[7]
Santiago, Chile	+ 3				[8]
Valparaiso, Chile	+ 6				[8]
Montevideo, Uruguay	+ 4				[8]
Rio de Janeiro, Brazil	+26	+1	+6		[8]

The important thing about these corrections is not that they are large but that they are all positive. This is most likely due to a difference in personal equation in observing transits of the Moon and stars at these stations and at Greenwich. The position of the Moon used in the reductions was obtained from corresponding observations made at Greenwich.

In any event, use of the lunar methods had the effect of placing stations systematically to the east. Since the longitude found by BÖRGEN and COPELAND requires a correction of the same order as that required at other stations, it follows that no shift in the longitude of Greenland is indicated.

South America: Longitude--It was found in 1926 by five South American observatories that the radio longitudes indicated a correction of -1^s to the conventional longitudes. This was verified by subsequent work at Santiago, La Plata, and Cordoba.

The conventional longitudes rested on determinations by cable made in 1874-84 by Lieutenant Commanders GREEN and DAVIS of the United States Hydrographic Office [9]. Two lines were run to South America: One via Key West, Havana, Santiago de Cuba, Panama, and the Pacific Coast; the other via Greenwich, Lisbon, Cape Verde Islands, and the Atlantic Coast. Both lines terminated at Cordoba and the closing error was $0^s.05$.

We have seen, however, that even in the short distance by cable between Greenwich and Paris systematic errors of $0^s.4$ occurred. In each of the lines to South America there were about ten stations and the possibility of an accumulated error of 1^s is not at all unreasonable. The closing error was, of course, remarkably small but the same systematic effect could have operated in both lines.

The Cuban longitudes were redetermined by the Hydrographic Office [10] in 1912. The longitude of Morro Lighthouse, Havana, was practically the same as for the earlier survey in 1875. The final longitude of Blanca Battery, Santiago, however, was found to be $0^s.44$ smaller. In the survey of 1875 there were 470 miles of cable between Havana and Santiago. The second survey used no cable and had the advantage of superior instruments. The two determinations indicate an apparent east-west expansion of Cuba of over 500 feet in 37 years. The possibility of such an expansion being undetected appears to be out of the question, and we must conclude that the earlier determinations of longitude required a correction of $-0^s.44$ by the time Santiago was reached.

Hence, insofar as the determinations by cable are concerned, we see that the discrepancy in one of the lines is cut almost in half, and that systematic errors are present which are known to be large enough to account for the remaining discrepancy.

Greenland: Latitude--Sabine Island is situated 8° north of the Arctic Circle and the determination of its latitude is very difficult. JELSTRUP, who used TALCOTT'S method, observed with the Sun above the horizon. Only five pairs were observed altogether, and in some cases the two stars transited almost two hours apart. The probable error of his final latitude, ±0″.5, is large and illustrates the difficulties encountered. Because of the uncertain day-minus-night term and other causes the latitude may easily be systematically in error by 1″ or more.

The latitude found by BÖRGEN and COPELAND is even more uncertain, as it was obtained from absolute measures of the altitude of the Sun and Polaris. They were not sure of the refraction to use in the reductions. The latitudes from two series of solar observations differed by 11″. The final latitude, derived from these two series and another of Polaris, is 3″ larger than JELSTRUP'S. These series, however, were very unequally weighted. Equal weights reduces the discrepancy to 0″.2.

Because of the difference in methods employed and because of the difficulties mentioned it is considered that even 3″ is much less than the errors of observation, and no definite change in the latitude of Greenland is indicated.

North America: Latitude--The United States Coast and Geodetic Survey redetermined the latitudes of three stations in 1930. The stations and the dates of the first epochs are: Mt. Tom, Massachusetts, 1862; Mt. Pleasant, Maine, 1851; Des Moines, Iowa, 1869. Reductions were made with the same stars being used for the two epochs at each station [11]. The proper motions were taken from BOSS' Preliminary General Catalogue (PGC) and no corrections were made for variation of latitude. The mean value of the differences in latitudes, new minus old, equals -0″.7.

The PGC proper motions require a systematic correction, and the value derived for the stars observed, on the basis of a paper which will appear shortly [12], is +1″.0 per century. Half of this amount is the correction used to reduce PGC to the modern system of the FK3 and half is due to a magnitude effect recently discovered. Correcting the latitudes of 1930 for the polar motion will reduce them by 0″.1.

After corrections due to proper motion and polar motion in 1930 are applied we find that the difference in latitude, new minus old, becomes -0″.1. This is far less than the errors of observation; the uncertainty due to the polar motion alone at the earlier epochs is ±0″.3.

The indicated changes in the latitudes of the individual stations average ±0″.8. Such changes are well within the errors to be expected. These are due to: (a) Different instruments; (b) different observers; (c) different observing sites; (d) unknown polar motion at the early epochs; (e) anomalies of refraction not eliminated in a short observing period; (f) errors in the proper motions.

Conclusion--No evidence has been found from astronomical observations to indicate that any continent has shifted. If any shifts have occurred they are less than the errors of observation.

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U. S. Naval Observatory,
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NOTES AND PERSONALIA

(See also pp. 196, 204, 219, 223, 224, 248, 265, 274, 297, 300, and 304)

NOTES

Earthquake observers wanted--The United States Coast and Geodetic Survey invites and urges members of the American Geophysical Union in the western mountain or Pacific Coast states to consider themselves volunteer observers in reporting earthquake effects to the Washington Office or to the San Francisco Office of the Bureau. The following addresses should be used:

Director, United States Coast and Geodetic Survey,
Washington 25, D. C.

Chief, Seismological Field Survey,
United States Coast and Geodetic Survey,
214 The Old Mint Building,
San Francisco 3, California

The Survey is the agency of the Federal Government authorized to make earthquake investigations. The success of its Information Service is dependent on securing reports from large numbers of scientifically minded individuals whenever they or their neighbors experience earthquakes. Forms may be obtained from either of the offices named. No postage is required in submitting reports on these forms.

The purpose of the program is to provide sufficient data to make possible the construction of isoseismal maps showing the distribution of intensity throughout seismically affected areas. The intensity is based on information furnished by observers, the evaluation being made with the aid of an intensity scale which associates certain groups of observable earthquake phenomena with specific intensity designations. (Thus, the Modified Mercalli Intensity Scale of 1931 has 12 degrees of intensity, the first of which is perceptible only under special circumstances; VI is the lowest grade for which destruction of property is indicated, and XII the most violent and widespread type.) The intensity evaluations are made by Bureau seismologists. Isoseismal maps are of value in estimating the focal depth of an earthquake, and in revealing variations in geologic structure since different structures respond in different degree to the passage of seismic waves. Also, quite a few weak shocks, too far from any seismograph to make a satisfactory record, miss detection altogether unless reported by local observers.

The information desired from observers includes earthquake effects on residents, movable inside and outside objects, buildings and other structures, streams, wells, etc. In fact, every type of phenomena associated with an earthquake such as earth sounds, lights in the sky, visible ground waves, and so on, should be reported.

In case an earthquake is important enough to justify the preparation of a preliminary report, observers are furnished copies, but otherwise the results are summarized in the annual seismological report of the Coast and Geodetic Survey.

Exchange of seismological bulletins--Seismologists in this country report that several European seismological organizations are endeavoring to reestablish the routine exchange of seismological bulletins as early as possible. Those who have discontinued the sending of such bulletins because of the war are urged to send current and back numbers to The International Seismological Summary, University Observatory, Oxford University, England; and to Professor J. Rothe, Acting Secretary, International Seismological Association, Boulevard de la Pyramide, Clermont-Ferrand (Puy-de-Dome), France. Professor Rothe is making every effort to reestablish the routine developed by his father, the late Professor E. Rothe, at Strasbourg.

Seismological files of Harry Fielding Reid--The archives of the United States Coast and Geodetic Survey have become the depository of the seismological files of the late Harry Fielding Reid.

Course in geochemistry--One of the most notable advances in geophysical instruction during the past school year was a course in general geochemistry given at the Graduate School of the Department of Agriculture, Washington, D. C. The course, taught by Dr. Hardee Chambliss, formerly Professor of Chemistry at the Catholic University of America and now consulting chemist for the Geophysical Instrument Company, Arlington, Virginia, met with gratifying response, particularly in view of it being the first of its kind to be offered in North America. Plans for the coming year indicate that its reception by students has made considerable impression upon the administration of the school.

Transactions, American Geophysical Union Volume 26, Number II October, 1945

EARTHQUAKES, ATMOSPHERIC PRESSURE, GEOLOGICAL STRUCTURE

V. Conrad

Abstract

The method of investigating the influence of pressure-variations upon release of earthquakes is given. Records of the barometric readings at a place in the earthquake-region for $07^{h}00^{m}$ are used for the second day before the quake (p_2), for the first day before (p_1), and for the day of the quake itself (p_0). Differences ($p_1 - p_2$) and ($p_0 - p_1$) are computed. Positive differences indicate rising pressure-tendency. Differences smaller than one millibar are taken as zero.

The following nine combinations are possible:

$$\begin{array}{lccccccccc} (p_1 - p_2): & + & + & + & 0 & - & - & - & 0 & 0 \\ (p_0 - p_1): & + & - & 0 & + & - & + & 0 & - & 0 \end{array}$$

The first four pairs of signs represent a rising tendency, the second four a falling tendency, while the last pair is neutral. This classification, taken from an earlier paper [see 1 of "References" at end of paper] of the author and from the two papers by F. BARON NOPCSA [2], is critically discussed and retained for the sake of continuity. It was found in a statistical investigation [1] of 45 Hungarian earthquakes that there were two types of quakes as indicated below.

Type I pct	Type II pct	
89	0	At rising tendency
7	94	At falling tendency
4	6	At neutral conditions

The epicenters of Type I are, for the most part, located in the lowland of Hungary, the epicenters of Type II in the mountainous regions bordering the lowlands. This behavior agrees exactly with the working hypothesis of NOPCSA which was worded by the author as follows: "Stronger atmospheric pressure-variations can be considered as trigger-causes of earthquakes if their tendency (rising, falling) supports the dynamical tendencies caused by the geological structure."

The results were encouraging but the data related to only 45 earthquakes which was too small a number to be conclusive. The investigation of new material [3] covering 23 years, providing data on 292 earthquakes, is reported in the present paper.

There may be an epicenter with f_+ earthquakes at rising tendency, and f_- at falling tendency, within the period of record. An index, $[100(f_+ - f_-)/(f_+ + f_-)]$, variable from +100 to -100, is the measure of the average reaction of an epicenter to rising or falling tendencies as far as frequencies are concerned. On the other hand, there are 142 epicenters with just as many earthquakes. In this case the geographical coordinates of the epicenters--located in one and the same degree-square--are averaged. A point, so defined, represents the average epicenter of the respective degree-square. The index is based on the epicenters with only one quake during the period of record in a degree-square and is related to its average epicenter. Thus, the results can be given in two tables. The first contains the epicenters with two or more quakes (multiple epicenters), the second shows the average epicenters for the different degree-squares. Either table contains the indices related to the epicenters. In the following, only the index signs are taken into consideration.

The discussion starts from a third table of 25 multiple epicenters of which at least two lie in one and the same degree-square. The epicenters of six squares show equal signs and those of [illegible] four squares have different signs. The question is whether or not this behavior is compatible with the working hypothesis. One cannot say a priori that the signs within a degree-square must in any case agree with one another even if the working hypothesis were valid. One degree-square is a rectangle of about 47 by 69 miles and covers an area of 3265 square miles at an average latitude for Hungary. Therefore, considering the size of a degree-square, there is no reason why a change of the geological structure should not occur within this area. Thus, the 25 individual index-signs have to be discussed from the point of view of the working hypothesis. The results may be stated as follows: (A) Four degree-squares with epicenters whose indices show different signs. Of these, two squares show a full agreement with the hypothesis, one epicenter could not be located with certainty in a third square so that agreement can only be surmised; from three epicenters of the fourth square, located in the Tisza Basin, one shows the positive sign demanded by the hypothesis, while two are characterized by negative signs, which is in contradiction to the hypothesis. (B) There are six squares with epicenters whose indices show the same sign. Of these, five squares indicate full agreement with the hypothesis and an agreement can only be surmised in the sixth square since the type of the subterranean geological structure could not be accurately identified. (C) Only two of 25 cases are strictly contradictory to the hypothesis.

Finally the index-signs of individual and of average epicenters are represented geographically. The inferences drawn from a map of these are given below.

(1) The distribution of negative and positive signs is apparently not a random distribution, but is systematically arranged. This is perhaps the most important conclusion.

(2) In three regions, which can be characterized as sedimented depressions, the epicenters react to rising tendency of atmospheric pressure in agreement with the hypothesis. The reaction mentioned above as being contradictory to the hypothesis of epicenters in the Tisza Basin proper, seemingly the very type of a Quarternary basin, is extended over a whole strip between the longitudes of about 19-1/2° and 21° east. Even these contradictory signs show a mutual position that is rather inconsistent with a random distribution.

(3) The epicenters in the mountain ranges proper react nearly unequivocally to falling-pressure tendency.

(4) On the whole, the reaction of 87 per cent of the epicenters is in agreement with the working hypothesis.

(5) A study of Californian epicenters concerning their reaction to pressure-tendencies could promote the knowledge of the present problem.

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[3] Kindly supplied by A. RETHLY of Budapest.

[Note: The complete paper is to be published in a forthcoming number of the Bulletin of the Seismological Society of America.]

Blue Hill Meteorological Observatory,
Harvard University,
Milton, Massachusetts

(Abstract received May 6, 1945; presented by FRANK NEUMANN at the
Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945.)

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INFLUENCE OF RESERVOIR-LOADING ON EARTHQUAKE-ACTIVITY IN THE BOULDER DAM AREA

Dean S. Carder

Abstract

Since the reservoir behind Boulder Dam started to fill in 1935, several hundred small earthquakes have been felt in the adjacent area and several thousand have been recorded since the first seismograph was installed at Boulder City early in 1938. Epicenters of several hundred of the latter have been located, in large part along known or suspected faults on the southern margins of the large lower basin in the reservoir. It is believed that the crustal block upon which this section of the reservoir rests has been tilted downward several inches along these faults and that the granitic massif south of the faults has not partaken in the downward movement. It is known that settlement of areas of sedimentary and volcanic rocks near the lake is somewhat greater than similar areas of granitic rock. It is believed that this settlement is the cause of large numbers of the local shocks partly because the peak occurrence-distribution is usually associated with peak seasonal loads in the reservoir.

Location of epicenters of local earthquakes has been possible through the means of three seismological stations using temporary equipment and later, by means of small-model BENIOFF seismographs, placed in a triangular net about Lake Mead, and a fourth supplementary station at Boulder Dam. Seismological work is carried on through a cooperative program between the United States Bureau of Reclamation and the United States Coast and Geodetic Survey with the assistance of the United States National Park Service. Similar programs are under way at Shasta Dam and at Grand Coulee Dam.

[Note: The complete paper is to be published in the October 1945 number of the Bulletin of the Seismological Society of America.]

U. S. Coast and Geodetic Survey,
Boulder City, Nevada

(Abstract received May 10, 1945; complete paper presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945.)

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(See also pp. 190, 212, 216, 240, 266, 302, 314, and 324)

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NOTES AND PERSONALIA

(See also pp. 196, 200, 219, 223, 224, 248, 265, 274, 297, 300, and 304)

PERSONALIA

Walter S. Adams, Director of Mount Wilson Observatory of the Carnegie Institution of Washington, was awarded an honorary degree of Doctor of Science by the University of Chicago in June 1945.

Earl T. Apfel has recently been appointed Chairman of the Department of Geology at Syracuse University to succeed George B. Cressey, who recently resigned.

J. D. Bardsdale has been on overseas duty as a Lieutenant Commander with the Navy. He is now back in the United States and stationed at San Diego.

Tom. F. W. Barth, Member of the American Geophysical Union in Oslo, Norway, writes that he is anxious to receive word of the progress of the Union during the long and dark years of occupation. Norwegian science has suffered severely from complete isolation, and they are eager to learn what has happened to scientific life elsewhere. Dr. Barth's address is Universitetets Mineralogiske Institutt, Blindern, Oslo, Norway.

C. H. Behre, Jr., of Columbia University has been cited by the University of Chicago as a Distinguished Alumnus.

Marland P. Billings of the Department of Geology, Harvard University, has been in Vermont studying talc deposits.

Word has come that Trigve Braarud, H. H. Gran, and Johan Hjort of Universitetets Biologishe Stasjon, Drøbak, of the University of Oslo, Norway, have survived the difficulties of enemy occupation and are now resuming their peace-time activities.

R. C. Briggs, principal assistant to the District Engineer of the United States Geological Survey in California, has been assigned for a year's detail to the Venezuelan Government as advisor in hydrology. The Venezuelan Government has in prospect setting up a stream-gaging and hydrologic organization. Mr. Briggs' headquarters will be at Caracas.

Ebbe Bronniche has been Acting Secretary of the International Council for the Exploration of the Sea since the death of W. Nellemose.

Walter H. Bucher of the Department of Geology, Columbia University, and Vice-President of the American Geophysical Union, is in Venezuela at the invitation of the Government of Venezuela to direct the preparation of a tectonic map of the country. He will return to his post at Columbia University in October or November 1945.

F. W. Cater, Jr., and F. G. Wells visited "El Monstro" (Parícutin) on their way back to Washington from the Pacific Coast.

Henry C. Cortes of Dallas, Texas, recently was elected President of the Society of Exploration Geophysicists.

George B. Cressey of Syracuse University is engaged in special work at the School of Humanities, Stanford University.

Odd Dahl, Member of the Union in Bergen, Norway, has written that fortunately he was able to carry on his work in applied physics with the Chr. Michelsens Institutt, relatively undisturbed during the war.

W. F. Foshag of the National Museum, O. H. Gish of the Carnegie Institution of Washington, and L. C. Graton of Harvard University, accompanied by Ezekiel Ordoñez, dean of Mexican geologists, have been studying the Volcano Parícutin with the aid of an Army helicopter. The helicopter has saved a great deal of time and effort in reaching out-of-the-way points of the shifting activity.

R. M. Garrels has returned from the Pacific theatre, where he has been in an assignment with the Military Geology Unit of the United States Geological Survey. He will return to his duties in the Department of Geology, Northwestern University.

Cecil H. Green of Dallas, Texas, was recently elected Secretary-Treasurer of the Society of Exploration Geophysicists.

Charles K. Green of the United States Coast and Geodetic Survey has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to physical hydrography, chart construction, and tide-current phenomena.

Transactions, American Geophysical Union Volume 26, Number II October, 1945

THE VARIATION OF VORTICITY IN THE ATMOSPHERE

Edward V. Ashburn and Leonard L. Weiss

Abstract--The principle of conservation of vorticity with reference to an inertial frame is reviewed and its consequences on a rotating spherical Earth considered. It is shown that if the absolute vorticity of an atmospheric element were conserved,then the vertical component of the vorticity would vary if the absolute longitude and latitude were changed. Actually, in the atmosphere there are many factors that change the absolute vorticity of the fluid elements. The buoyant force (flotation-force), the baroclinic nature of the atmosphere, divergence-viscosity, turbulence, and non-adiabatic processes are some of the more important of these factors. Some of the ways in which the buoyant effect tends to change the vorticity are discussed here in qualitative terms. A method of attack is suggested for a more complete treatment of the motions of the Earth's air-cover.

Equations showing the relationship between the divergence and the time-rate of change of the vorticity are also given.

The wind-speed and direction of the fluid elements in the atmosphere can be represented by a vector-field. Any vector-field is completely determined and analytically specified by its divergence, curl, and boundary-conditions. The motion and deformation of any fluid element may be represented as the resultant of (1) a common motion of all particles of the element with the same velocity $\mathbb{V}$ (vectors are indicated by the use of double letters, thus, $\mathbb{V}$, $\mathbb{r}$,$\mathbb{\omega}$, $\mathbb{\Omega}$, etc.) as that of any one (rigid translation), and (2) relative motions between the particles within the element which may be expressed in terms of the divergence and curl.

The vector $\nabla \times \mathbb{V}$ is called the curl of the vector fluid-velocity, or the vorticity. It gives the "circulation at a point," just as the divergence gives the "rate of expansion at a point," and indicates the rotary element in the fluid motion, just as the divergence indicates the pure strain element.

For the visually minded, the curl and divergence have simple, physical meanings which are of great aid in the study by physical reasoning of some of the important features of fluid motion. After the reasoning has passed the qualitative stage, but before the quantitative study can be completed, it is necessary to define the curl and divergence as abstract mathematical quantities to which the usual methods of mathematical reasoning apply.

Any fluid motion which has vorticity is called "rotational" or vortical motion, and fluid motion which has no vorticity is known as "irrotational" or non-vortical motion. The simplest case of rotational motion is rotation as a solid (Figs. 1 and 2), where the angular velocity is constant

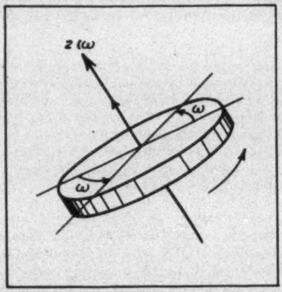


Fig. 1--Rotational motion, solid disk (ω = angular velocity; $\mathbb{\zeta}$ = vorticity = curl $\mathbb{V} = 2\mathbb{\omega}$; magnitude of $\mathbb{\zeta} = 2\omega$; direction along axis)

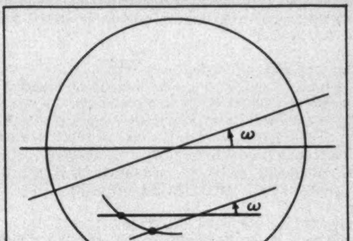


Fig. 2--Rotational motion, solid disk (Rotating with angular velocity ω has the same vorticity at all points)

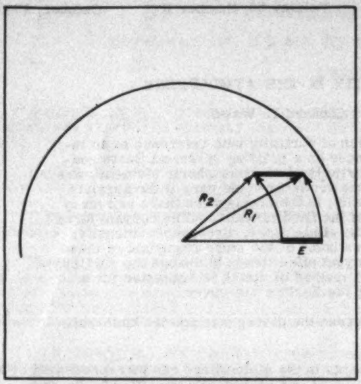


Fig. 3--Irrotational motion, the VR-vortex for fluid disk (Definitions: VR = constant; E = element considered with orientation fixed in space)

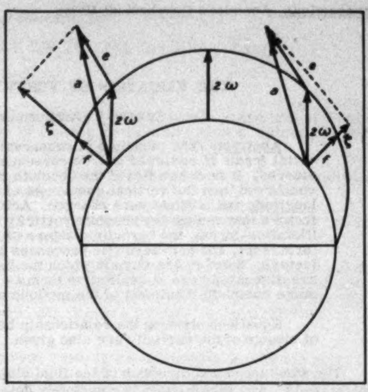


Fig. 4--Conservation of absolute vorticity $(f + \zeta) \neq$ constant

throughout the solid. For this case it can be shown that

$$\nabla \times \mathbb{V} = 2\,\omega$$

where ω is the angular velocity.

A simple case of symmetrical irrotational motion is the VR-vortex, in which the scalar magnitude of the velocity times the radius is a constant. The VR-vortex is irrotational and has zero-vorticity everywhere except at the center where the velocity is infinite (see Fig. 3).

The vorticity of the atmospheric element relative to a set of coordinates whose axes do not rotate relative to the fixed stars, may be considered to be the sum of two components, namely, (1) the vorticity of the element relative to the Earth (see Fig. 4), and (2) the vorticity of the Earth, or

$$\nabla \times \mathbb{V}_a = \nabla \times \mathbb{V}_r + \nabla \times (\Omega \times \mathbb{r})$$

where $\mathbb{V}_a$ is the vector-velocity relative to absolute space, $\mathbb{V}_r$ the vector-velocity relative to the Earth, Ω the vector angular velocity of the Earth, and r the radius-vector from the center of the Earth to the element.

It may be shown that in a non-viscous fluid in motion under the action of external forces which have a potential, and in which the density is constant or a function of the pressure only, that vorticity can be neither created nor destroyed. In the atmosphere, these conditions are not fulfilled and vortices are constantly forming, altering, and disappearing. As a first approximation, it may be useful to investigate the variation of the relative vorticity of an atmosphere composed of a barotropic inviscous fluid. In this case the absolute vorticity would remain constant. However, the vertical component would not remain constant because the vertical axis passing through the fluid element is constantly changing its direction. This is illustrated in Figure 4.

Note that the frame to which the vorticity which is conserved must be referred is non-rotating with reference to the fixed stars. The Earth's vorticity is constant and equal to 2Ω (see Fig. 4). If a rotating column is included in the system where ω is its vorticity with reference to the Earth's surface, then the absolute vorticity of the system is $2\Omega + \omega = \omega_a$. It is this vorticity ω_a which is conserved. It is readily seen from Figure 4 that the component of ω_a normal to the Earth's surface is not constant. Let ζ be the vertical component of ω, and f the component of 2Ω vertical to the Earth's surface, then

$$(f + \zeta) \neq \text{Constant}$$

except in the special case where the column moves westward at the same velocity that the Earth's surface moves eastward [see 1 to 4 of "References" at end of paper].

The qualitative reasoning given above can be put into analytical terms as follows:

If the theorem of CORIOLIS is applied to the absolute vorticity, we have

$$\left(\frac{d}{dt}\nabla\times\mathbb{W}_a\right)_{\substack{\text{absolute}\\ \text{coordinates}}} = \left(\frac{d}{dt}\nabla\times\mathbb{W}_a\right)_{\substack{\text{relative}\\ \text{coordinates}}} + \Omega\times(\nabla\times\mathbb{W}_a)$$

If it is assumed that the absolute vorticity is conserved then

$$\left(\frac{d}{dt}\nabla\times\mathbb{W}_a\right)_{\substack{\text{absolute}\\ \text{coordinates}}} = 0$$

and since $\Omega\times(\nabla\times\mathbb{W}_a)$ is not equal to zero except when $(\nabla\times\mathbb{W}_a)$ is parallel to Ω, then the vorticity relative to the surface of the Earth must change in the direction of $(\nabla\times\mathbb{W}_a)\times\Omega$ which would mean that the vertical component would change. Therefore

$$(f+\zeta)\neq\text{Constant}$$

ROSSBY derived the expression $(f+\zeta) = \text{Constant}$ by using the form of the equations of motion in which the curvature of the Earth is neglected, and hence in which the direction of the vertical does not change over the surface of the Earth. For most purposes for which this form of the equations of motion is used, it is only the change of position on the Earth that is of consequence, so that these equations are sufficiently valid over fairly large areas. However, in the discussion of absolute vorticity the change in direction of the vertical in absolute space is also involved, which is quite rapid because of the rotation of the Earth. Hence for the discussion of vorticity the form of the equations of motion used by ROSSBY is a poor approximation.

If the absolute vorticity were conserved, the vertical component would vary as the fluid element moved relative to the Earth and as the Earth rotated. Figure 5 shows how the magnitude of the vertical component of the absolute vorticity would change for a fluid element starting at latitude 50°, as the latitude and absolute longitude changed. For example, if a fluid element starting at latitude 50° moved to latitude 30°, and the absolute longitude were changed 180°, the vertical component of the absolute vorticity would then be -0.174 of the vertical component at its reference-position at latitude 50°. Figure 6 shows how the vertical component of the vorticity would change for a fluid element starting at latitude 30°, and Figure 7 for a fluid element starting at latitude 70°. This shows that the change in the vertical component of the absolute vorticity would be a function of the change in absolute longitude if the absolute vorticity were conserved.

Figure 8 shows how the rate of change of the vertical component of the absolute vorticity would vary if the fluid element remained at latitude 50°. When the absolute longitude changed 90°, the vertical component of the absolute vorticity would be changing at the rate of 33 per cent per three hours.

The absolute vorticity in the real atmosphere is not conserved because a buoyant force (flotation-force) acts to prevent the large-scale vertical motion that would result. This force acts to change continually the direction of the absolute vorticity-vector. Figure 9 illustrates the operation of this force. In the most general case of fluid motion there are five forces which may act on a fluid element. They are: External forces (gravity in this case); pressure forces; inertia forces; viscous forces; and elastic forces. Only the influence of the first has been considered here. Only if the combination of the extraneous forces were of exactly the right magnitude to keep turning the axis of ω so that it continued to be normal to the Earth's surface, could $(f+\zeta)$ remain constant, and it remains to be shown whether or not this is the case. However, it seems a priori to be extremely unlikely.

The over-all effect of the buoyant forces acting on the rotating column is to introduce a couple whose torque-axis is perpendicular to the column and parallel to a tangent to the Earth at the base of the column. The column as a whole then tends to precess in such a fashion as to swing the vorticity-axis into line with the torque-axis.

The relation between the vorticity and the divergence can be shown in the following manner:

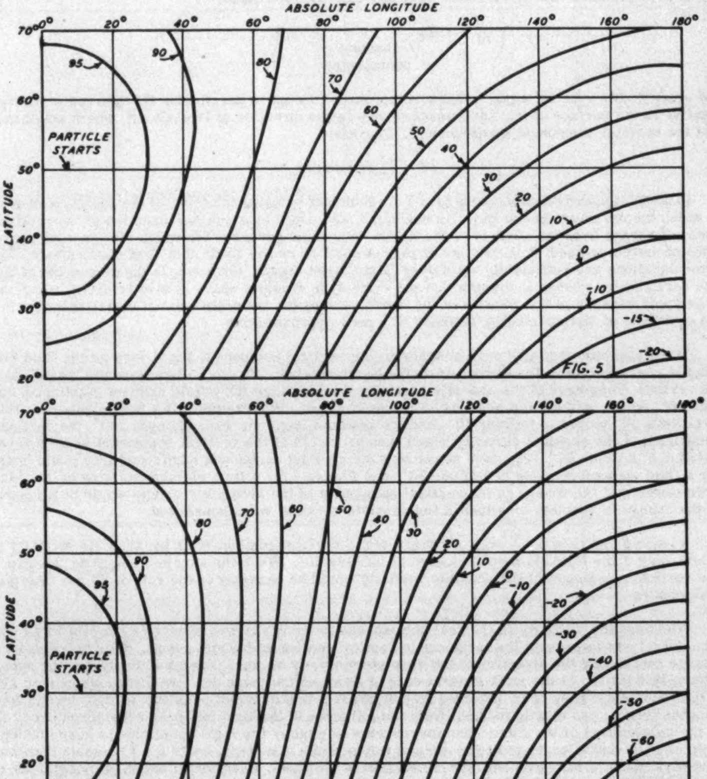
The equation of relative motion of an inviscous fluid may be written,

$$\dot{\mathbb{W}}_r = -\nabla\phi - \alpha\nabla P + \mathbb{W}_r \times 2\Omega \qquad \text{.......................(1)}$$

in the usual notation.

If the operator $\nabla\times$ is applied we have

$$\nabla \times \dot{\mathbb{W}}_r = -\nabla\alpha \times \nabla P + \nabla \times \left(\mathbb{W}_r \times 2\Omega\right) \qquad \text{.......................(2)}$$



Figs. 5 and 6--Changes in vertical projection with absolute latitude and longitude, particle starting at latitude 50° for Figure 5 and at latitude 30° for Figure 6 (Curves are change of projection in per cent)

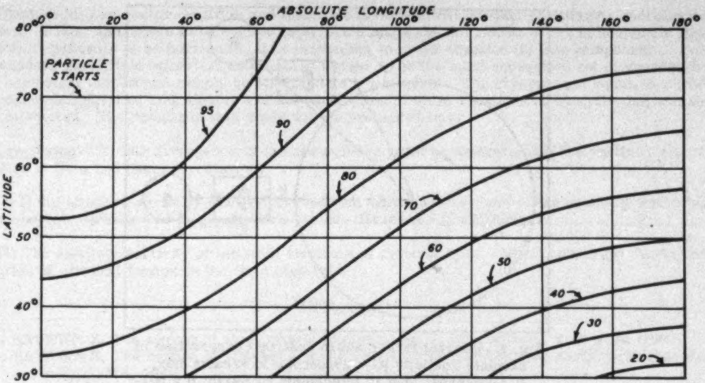


Fig. 7--Change in vertical projection with absolute latitude and longitude, particle starting at latitude 70°
(Curves are change of projection in per cent)

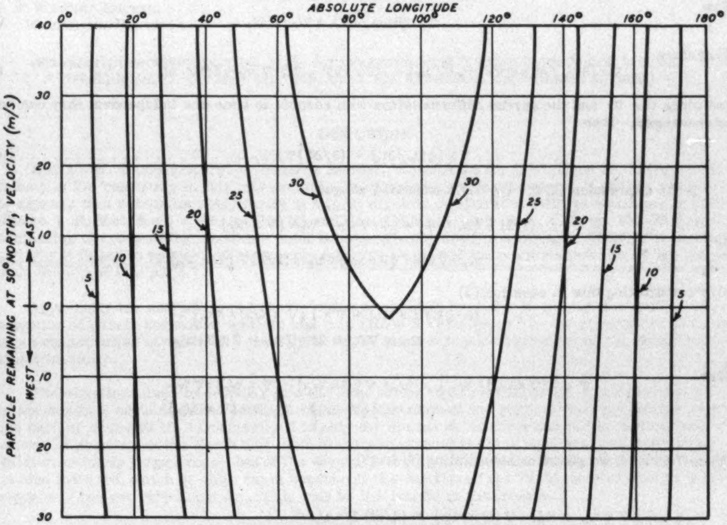


Fig. 8--Percentage-change per second of vertical projection of initial value of vertical vorticity times 10^{-4}

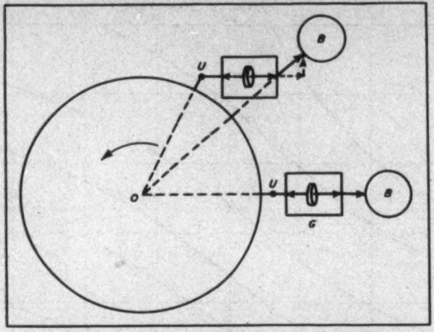


Fig. 9--Buoyant forces act to destroy conservation of absolute vorticity (G = gyroscope in vacuum-box; U = universal joint in attachment to Earth; B = balloon buoyed up by Earth's atmosphere)

$$\nabla \times \dot{\mathbb{W}}_r = -\nabla\alpha \times \nabla P + 2\Omega \cdot \nabla \mathbb{W}_r - 2\Omega \nabla \cdot \mathbb{W}_r \qquad (3)$$

Now

$$\dot{\mathbb{W}}_r = (\partial \mathbb{W}_r / \partial t) + \mathbb{W}_r \cdot \nabla \mathbb{W}_r \qquad (4)$$

Therefore

$$\nabla \times (\partial \mathbb{W}_r / \partial t) + \nabla \times (\mathbb{W}_r \cdot \nabla \mathbb{W}_r) = -\nabla\alpha \times \nabla P + 2\Omega \cdot \nabla \mathbb{W}_r - 2\Omega \nabla \cdot \mathbb{W}_r \qquad (5)$$

and since the $\nabla\times$ and the partial differentiation with respect to time are independent they can be interchanged. Then

$$\nabla \times (\partial \mathbb{W}_r / \partial t) = (\partial/\partial t) \nabla \times \mathbb{W}_r \qquad (6)$$

If the expression $(1/2)\nabla(\mathbb{W}_r \cdot \mathbb{W}_r)$ is expanded we get

$$(1/2)\nabla(\mathbb{W}_r \cdot \mathbb{W}_r) = \mathbb{W}_r \cdot \nabla \mathbb{W}_r + \mathbb{W}_r \times (\nabla \times \mathbb{W}_r)$$

or

$$\mathbb{W}_r \cdot \nabla \mathbb{W}_r = (\nabla \times \mathbb{W}_r) \times \mathbb{W}_r + (1/2)\nabla(\mathbb{W}_r \cdot \mathbb{W}_r)$$

Now substituting this in equation (5)

$$\begin{aligned}(\partial/\partial t)\nabla \times \mathbb{W}_r + \nabla \times \left[(\nabla \times \mathbb{W}_r) \times \mathbb{W}_r\right] &= \\ -\nabla\alpha \times \nabla P + 2\Omega \cdot \nabla \mathbb{W}_r - 2\Omega \nabla \cdot \mathbb{W}_r & \qquad (7)\end{aligned}$$

Now

$$\begin{aligned}\nabla \times \left[(\nabla \times \mathbb{W}_r) \times \mathbb{W}_r\right] &= \mathbb{W}_r \cdot \nabla(\nabla \times \mathbb{W}_r) - (\nabla \times \mathbb{W}_r) \cdot \nabla \mathbb{W}_r \\ &+ (\nabla \times \mathbb{W}_r)(\nabla \cdot \mathbb{W}_r) - \mathbb{W}_r \nabla \cdot (\nabla \times \mathbb{W}_r) \qquad (8)\end{aligned}$$

Since $\nabla \cdot \nabla \times \mathbb{W}_r = 0$ we get after substituting (8) in (7)

$$\begin{aligned}&(\partial/\partial t)\nabla \times \mathbb{W}_r + \mathbb{W}_r \cdot \nabla(\nabla \times \mathbb{W}_r) = (d/dt)\nabla \times \mathbb{W}_r = \\ &-(\nabla \times \mathbb{W}_r)\nabla \cdot \mathbb{W}_r + (\nabla \times \mathbb{W}_r) \cdot \nabla \mathbb{W}_r - \nabla\alpha \times \nabla P + 2\Omega \cdot \nabla \mathbb{W}_r - 2\Omega \nabla \cdot \mathbb{W}_r \qquad (9)\end{aligned}$$

Equation (9) is a vector-equation and therefore invariant with respect to differing coordinate-systems. If this equation is to be applied to synoptic maps and the motion of the atmospheric fluid-elements is assumed to be horizontal, it is convenient to break equation (9) into components. For our purposes geocentric spherical coordinates appear to be the most convenient set of coordinates, since horizontal motion can simply be specified as r = constant. The expansion of equation (9) into the geocentric spherical coordinates and the application of these equations to synoptic maps is now being attempted. The results of this study will be presented later.

Conclusion--(1) The divergence in the atmosphere could be determined if the vorticity and its variation in time and space were known.

(2) If the absolute vorticity were conserved, the vertical component of the vorticity would vary as the absolute latitude and longitude were varied. Hence $(f+\zeta) \neq$ Constant.

(3) The absolute vorticity of the fluid elements of the atmosphere is not conserved due to the operation of external forces on the fluid elements.

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DISCUSSION

EDGAR W. WOOLARD (U. S. Weather Bureau, Washington 25, D. C., June 15, 1945)--I see no fallacy in the reasoning in this manuscript. To clinch the matter, however, it still is necessary to express this reasoning analytically in a form directly comparable with the equations of ROSSBY [Quart. J. R. Met. Soc., v. 66, pp. 70-71] and HAURWITZ [J. Mar. Res., v. 3, pp. 255-256], and by comparing corresponding equations point out specifically what is missing in ROSSBY'S equations and why it failed to appear. (Presumably this will be part of the work referred to by the author near the top of this page.)

Apparently the assumption of conservation of absolute vorticity is inconsistent with the assumption of purely horizontal motion, and it is SHAW'S "resilience" of the atmosphere that prevents conservation of vorticity. Gravity in itself, since it is a conservative force, should not affect vorticity.

The equations used by ROSSBY are the form of the equations of motion in which the curvature of the Earth is neglected, and hence in which the direction of the vertical does not change over the surface of the Earth. Ordinarily it is only the change in the direction of the vertical with change of position on the Earth that is of consequence, so that these equations are sufficiently valid over fairly large areas; but if the change in the direction of the vertical in absolute space is also involved, which is quite rapid because of the rotation of the Earth, then of course these equations are not very accurate. This may be the source of the trouble.

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(See also pp. 190, 203, 216, 240, 266, 302, 314, and 324)

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SOME ASPECTS OF EQUATORIAL WEATHER AND OF THE TYPHOON PROBLEM

Charles E. Deppermann

In the first week of the War in December, 1941, there were published in Manila 500 copies of a new monograph of mine entitled "Upper-air characteristics (1-4 km) of the Philippine and adjacent regions." There was time only to distribute a few copies to Navy and Pan-American Airways men; the rest were successfully hidden from the Japanese, though the hiding place had to be changed thrice. Unfortunately, however, though endeavors were made before internment to save the papers by distribution to others, absolutely all copies seem to have been burned either in the siege of Manila or at Corregidor; not one has so far been recovered in spite of diligent search by both Army and Navy men. There were also burned the original and carbon copies of the manuscripts of seven other original articles which I had composed during occupation of Manila by the Japanese before I was actually interned at Los Baños in July, 1944. Due to the imminent danger of search, none of these could be taken with me to the internment camp, for they would have been seized and translated into Japanese like all my other monographs, and used for hostile purposes. They therefore had to be left in trustworthy hands in Manila, but they all perished in the flames of the siege together in some cases with their keepers.

But there is no use in crying over spilt milk, so we shall content ourselves with giving briefly the contents or results of the above papers, adding a few words as to the prospects of rewriting them.

The paper on upper-air characteristics was based on data regarding temperature, pressure, and humidity aloft obtained from meteorograph-records of Hong Kong, Singapore, Batavia, and Manila. As far as my recollection serves me, the following are the most important conclusions reached:

(1) As the typhoon-season approached, the trade-wind inversion gradually disappeared almost entirely due to convergence. This of course facilitated the formation of thunderstorms and all manner of upward convection. However, the relative humidity above the second kilometer seemed to remain below that of the southwest monsoon.

(2) The southwest monsoon retained its high moisture-content, with no inversion, up to at least the fourth kilometer. The lapse-rate was usually not much more than the wet adiabatic.

(3) At Hong Kong, during the winter months, there was usually a strong inversion at the base of the westerlies of the temperate zone, which served as an effective barrier to further upward convection, and gave a full covering of stratocumulus or altocumulus but comparatively little rain. Above the inversion the air was usually dry and clear.

(4) It was practically impossible to distinguish between different air-masses aloft at Singapore, the variations both in humidity and temperature being remarkably small. This seemed to be due to convergence, yet this is not a universal characteristic of equatorial air, as will be seen from the results for Batavia. For the prediction of rain, the convection-condensation level and air-stream convergence must be carefully considered.

(5) As already pointed out in a previous paper, Batavia air is by no means always very moist, and we can get air-streams there with characteristics much like those of the temperate zone, with considerable dryness aloft. The upper-air records seem to confirm the rather surprising statement of Java meteorologists that the daily upward convection affects merely the first kilometer or so of air.

The paper on wind-roses for the Philippines up to 15 km (manuscript only) was based on the as yet unpublished pilot-balloon observations for Aparri, Dagupan, Manila, Cebu, and Zamboanga, in the Philippines. These data, too, went up in the flames, and the monograph can not be reconstructed until sufficient new observations have been accumulated. Interesting features were the shallowness of the northers, the slope southward of the westerlies of the temperate zone as one goes aloft, and the seasonal variations of the southwest monsoon. A distinct lag was found in air-stream variation relative to the movement of the heat equator.

The paper on the upper-air circulation around typhoons (manuscript only) gave the average circulation, up to about 500 miles from the center, for large and small typhoons of the three prominent types, that is, trade-northers, trade-southwest monsoon, and triple-point. Since this paper used as data the pilot-balloon observations already mentioned, its reconstruction must regretfully be left until quite a later date. The main conclusions reached were:

(1) Trade-northers type--The trade occupies the right rear sector and its direction was rather close to that of the typhoon-path. The rainfall in this sector was found to be much less than in other parts of the storm. This trade-northers type corresponds more than the others of our region to the West Indian hurricane. The winds aloft in the southwestern portion of the typhoon, occupied by the northers, showed very little if any convergence.

(2) Trade-southwest monsoon type--The most remarkable feature of this type was the continuance of very strong wind-convergence aloft even to three or four km in the southwest portion of the storm, in strong contrast to the trade-northers type. Remember that above the first kilometer or two the northers and trade are usually rather dry, while the southwest monsoon remains wet. The conclusion seems warranted that the convergence in the latter type is due to upward convection caused by the condensation of the water-vapor of the monsoon. Rainfall is more evenly distributed than in the trade-northers type. It should be noted in passing that enough differences in wind-distribution aloft were found fully to justify the division of the data into the three types of typhoon.

(3) Triple-point type--In this type, convergence in the southwest sector is still strong aloft. The line of discontinuity between northers and southwest monsoon remains marked for at least three km, whereas that between trade and northers is not at all distinct, with the trade dispossessing the northers after the first few km.

Another striking result for all types is that the wind-velocities and convergence are strongest from the second to the fourth kilometer, which again appears to point to these levels as being the region of most violent condensation of water-vapor and the main region of origin of typhoon-energy. The circulation of the typhoon could of course be traced much higher in the strong typhoons as contrasted with the smaller ones, divergence of winds starting first in the right forward quadrant. The piballs confirm the conclusions reached from cloud-observations that in the Philippine Region the circulation of strong typhoons continues to great heights, ten km or so, well into the cirrus region. However, so very few observations were obtained aloft in the violent region of the typhoons that no conclusions could be drawn as to how far aloft the severe winds and turbulence extended.

The paper on the energetics of typhoons (manuscript only) especially endeavored to show the importance, in the tropics, of certain terms in the equations of motion which are not so important in temperate zones; hence the need of care in the use of simplified formulas often employed in the tropics. For instance: (1) As one approaches the equator, all simplified equations with the sine of the latitude in the denominator are misleading, since we know that infinite results are impossible. Isallobaric wind and other gradient equations, as given in PETTERSSEN'S book, have likewise to be reformed for use in the tropics. The first two equations of motion,

$$(dv_x/dt) + 2\omega(v_z \cos\varphi - v_y \sin\varphi) = -(1/p)(\partial p/\partial x) \quad \text{and} \quad (dv_y/dt) + 2\omega v_x \sin\varphi = -(1/p)(\partial p/\partial y)$$

are simplified by the insignificance of the sine-term, and the vertical-motion term containing the cosine of the latitude becomes important near the equator.

(2) There was also stressed the importance, for typhoon-formation and deepening, of the disappearance of the pressure exerted by the water-vapor when it condenses into heavy rainfall, if the strong rotational motion prevents its replacement by other air.

(3) Using HAURWITZ'S ideas of the levelling off of pressure at about the 10- to 12-km level, a model typhoon was constructed, assuming that near the center we have the (v/r)=constant type of vortex (v = velocity and r = distance from the center) until we get to the violent sector of strongest winds, and that then we change to the (vr = constant)-type of vortex as we proceed outward. The barometric curve of the typical typhoon is obtained, but the difference of temperature needed between the heated core and the cooler outer part of the storm aloft seems somewhat excessive and must certainly await confirmation from actual data.

The paper on the barometric fine structure at Manila (manuscript only) was a study of the small oscillations or deviations in pressure found on the tenfold magnified FUESS barograph-curves at Manila. These oscillations were of varied type and made a very interesting but at times puzzling study. Any adequate discussion, however, would need reproduction of actual curves of barometric pressure, and unfortunately all FUESS barograph-records were burned.

The paper on the origin of typhoons in the Marianas and Carolines (manuscript only) was an attempt to extend my studies of typhoon-origins to this region, using especially the data contained in the publications of the Japanese South Seas Bureau. Of interest are the following conclusions:

(1) The region around Truk seems a great breeding place for typhoons, the direction of the origin from Truk depending on the season.

(2) Many of the typhoons, at least in the wave-stage, if such there be, could be traced as far east as Jaluit, and even below Jaluit, Ponape, and Truk--hence below latitude 5° north.

(3) When in the incipient stage, the typhoon-path could be very irregular, indicating that its path could be determined even by air-currents near the surface.

The paper on the gusty southeast wind at Manila (manuscript only) explained the origin of this wind and gave practical rules for its prediction. Its importance lies in the fact that this wind proves dangerous at times for airplanes while starting or alighting. The wind was shown to be dependent upon the position of the trade wind high east of the Philippines.

The paper on the question, should virtual temperatures be used in the tropics? (manuscript only) showed that by using virtual temperatures on adiabatic charts instead of the usual dry-bulb temperatures, one may possibly get a fairer idea of conditions of stability, especially in the neighborhood of inversions.

It had been understood that the whole of the paper on relative humidity gradient and cloud bases would be published in the Proceedings of the International Union of Geodesy and Geophysics for the Washington Assembly in 1939. Unfortunately this could not be done. The original manuscript has since been lost, and my carbon copy perished in the flames at Manila. An endeavor will be made to restore and print the whole argument upon which the abstract printed in the Bulletin of the American Meteorological Society is based.

The paper on distribution frequency of thunderstorms in the Philippines (manuscript only) was based on daily maps of thunderstorm-frequency for either 1938 or 1939 (years for which I had made daily upper-air wind-charts for the paper on Upper-air circulation). From these charts a graph of monthly frequencies of thunderstorms for the Philippines was made. It contained some interesting maxima and minima, for instance, a rather unexpected minimum for August followed by a surprisingly high maximum for autumn before the expected drop to the winter minimum. Various explanations were tried, but all failed except a frontal-zone, or rather convergence-zone, one. The minimum for August is a natural consequence of the absence of the intertropical convergence-zone from the Philippines, being placed quite a distance to the northward. The autumn maximum comes with the appearance again of both the intertropical convergence-zone and the northers-trade wind shear-line in the Philippines. Winter thunderstorms appeared to be entirely frontal. We are not prepared to explain all thunderstorms on a frontal or convergence basis, but it would seem that at least a majority can be so explained.

In passing, it may also be noted that my entire collection of over 5,000 cloud-photographs, prints as well as negatives, was also lost in the ruins of Manila.

Summarizing, the following ideas are especially stressed in all the above mentioned papers:

(1) Convergence has vital importance in the equatorial region rather than differences of temperature, at least at the surface. This of course demands as a consequence a careful study of air-stream trajectories and emphasizes the supreme importance of maintaining very many pilot-balloon stations in this region. In line with this idea, we are at present trying to extend our studies of upper-air circulation to include Australia, China, the Carolines, the Solomons, and other areas in this region, provided enough material can be collected.

(2) Water-vapor and its condensation play a vital role in the tropics. Any studies of air-streams which neglect this important factor must of necessity limp in the tropics and be of very limited or even erroneous application. It is admitted that the dynamic equations as they stand,

using the thermodynamic water-vapor terms, are very difficult to handle, but we consider that the problem of their practical solution must be faced courageously if we are to make progress in understanding more fully the weather, not only of the equatorial region, but also of the temperate zone. It is considered that graphical methods of sufficient accuracy could be developed to satisfy the demand which must be squarely faced for the complete dynamic equations. We doubt if sufficient radiosonde observations will ever be on hand for the tropical region; hence increased attention should be given to cloud-study, and each raob should be accompanied by cloud-photographs.

(3) There is need of care in applying the ordinary meteorological equations to the tropics. The terms depending on latitude should be especially scrutinized.

(4) Studies of the different types of typhoons emphasize the need to curb the ever-present tendency to draw general conclusions too hastily and to group heterogeneous units into a common whole with danger of losing sight of very important distinguishing characteristics.

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SOME REMARKS UPON THE DESTRUCTIVE EFFECTS OF THE HURRICANE, SEPTEMBER 14-15, 1944, OBSERVED AT HYANNIS, CAPE COD, MASSACHUSETTS

V. Conrad

Only a few observations could be made during the hurricane in the night; the majority were made in the morning, after the hurricane-weather had been replaced by bright sunshine. In the following, some unpretentious remarks are given; so unassuming they are, that it would not have paid to study the immense literature in order to find out how far similar considerations had been made. Their value, if any, may lie in the fact that the inferences were drawn immediately from actual observations.

The voice of the hurricane--At 20^h45^m, on the evening of September 14, 1944, the speed of the wind increased from strong storm-force to dangerous intensities. Soon after 21^h the first electric pole fell on the main street. (The following morning this pole was found to be rather rotten at its base, so it was rather easily razed.) Evidently this event caused a great mechanical tension of the wires which facilitated the downing of other poles, so that through short circuits and wires parting, Hyannis was soon in full darkness. The acoustic impression until 21^h was the normal moaning and howling of a very strong storm. Afterwards the noise was no longer comparable with any, not even disturbed musical sound. The noise was much more like blows by a gigantic hammer at a not too high frequency. The branches of the trees and other objects knocking against one another might have caused this noise which drowned the ordinary howling.

Drifting with the storm--An old cottage, where the writer resided, was located immediately at the water's edge on a flat beach, facing south. There we experienced the benefit of the effective warning system of the United States Weather Bureau. A few hours before the hurricane developed fully, we were persuaded by the owner, IVAN L. MARTIN, to move into his house on the well-protected main street. When the writer visited the site of the cottage the next morning, the cottage had vanished, except for the underground garbage-receiver. Only the pantry could be found, lying on the ground on its rear wall, with the refrigerator (an old-fashioned Kelvinator weighing about 500 pounds) in its normal corner but of course not erect. The distance from the former location was 180 yards, measured by steps.

Perhaps 50 yards east of the old cottage a rather new, larger house had stood about nine feet higher on the western slope of the bluff. This house, too, had disappeared. Its roof was found on a heap of ruins close to the pantry mentioned. The distance from the original location was at least 200 yards.

About 250 yards from the shore line a small, rather new bungalow had been located. It had been moved 50 to 70 yards back and was stranded against an electric pole. The bungalow was damaged only slightly and apparently still habitable after its voyage.

Before the hurricane the bluff was so steep at its sea-side that it was boarded for some hundred yards. After the storm, the boarding had vanished and there was a smooth, sandy slope up to the crown of the bluff. This effect shows the huge energy of the invading surges and of the storm-tide.

The cases described are characteristic for much of the destruction close to the water-front. In the overwhelming majority of cases, the destruction was apparently caused by a joint effect of wind and water. The wooden houses are more or less water tight and are set above the ground on astonishingly few and slender pillars. When the level of the water rose as a consequence of the storm, the houses were lifted by their buoyancy, and with friction thus diminished, they sailed with the storm.

The center of gravity of such houses generally lies below the half of their height, perhaps in the lower third. The friction between house and ground is opposed to the pressure-forces of the storm so that a torque is caused around a horizontal axis through the center of gravity. Thus, the upper parts of a house go ahead of the lower parts, and the leeside and lower edge of the inclined building begins to plough the ground and the drift is stopped. Some objects showed this effect in a rather obvious manner. Minor structures, like smaller barns, were turned upside down in consequence of the torque mentioned above.

The main street of Hyannis runs from west to east. A great many of the big windows of the stores on its north side, looking southward, were broken, apparently by the enormous wind-pressure. On the other side of the street, hardly a window was broken.

A counterpart, in the physical sense, was presented by a large barn inland which was only slightly damaged. The large front and rear doors, however, were blown outward. In this case, the doors could not have fallen inward because of the interference of the door posts, but it was obvious that forces must have been pressing from within--a kind of explosion force well known in tornados. According to the weather-map of the United States Weather Bureau the fall of pressure toward the center of the storm was very intense. Nevertheless, the hypothesis is difficult to apply to pressure-conditions in a hurricane. The barn in question was of good construction, but seemingly not as tight as would be necessary for the development of an effective pressure-difference between the inside and outside. The phenomenon evidently must have caused a force directed outward. Long after these observations were originally written, the author learned by a letter from HANS NEUBERGER of State College, Pennsylvania, of another conception. He suggested that the doors may have been moved outward by the dynamic suction-effect of air-currents passing an obstacle. This idea should be thoroughly studied theoretically and experimentally. It is believed the preference should be given to a dynamic explanation.

The roof of a house on the bluff of West Yarmouth had glided down so far that its lee edge touched the ground. The boards on the windward side were partly removed, yet a lot of jars of preserved fruits standing on a shelf, in rank and file, were undisturbed as seen through the breach. Perhaps the storm had lifted the roof up until it glided down on the leeside. The immediate impression was that the assumption of a force directed outward, also in this case, combined with normal storm-effects, would explain more easily the complex picture of heavy destruction on the one hand and the untouched shelf of jars on the other. (Such things are common in destruction by tornadic winds.--Ed.)

Generally well-built new houses stood against the hurricane almost without major damage, except for the chimneys. A house close to the water-line must have strong foundations of concrete and a stream-lined roof, at least in the direction of hurricane-winds, to withstand the effects of such a storm. Gables facing the sea, frequently used, and attractive as they may be, are disadvantageous.

Huge trees, a yard and more in diameter, blocking highways and smashing roofs and fronts of large houses, made a deep and unforgettable impression. They seemed to give the best picture of the inconceivable forces of a hurricane. A glance at the limited damage to the surroundings of such uprooted giants, however, suggests that there may be an additional phenomenon to cause these enormous effects.

An attractive idea is that there is a resonance phenomenon which makes the hurricane-forces still more efficacious. The tree is the resonator and the frequency of its free oscillation is dependent upon its elastic properties and upon its dimensions. The exciter is represented by the turbulence (gustiness) of the storm; the frequency of the gusts increases with the velocity of the wind, and the more closely this frequency approaches that of the free oscillation of the tree, the more is its increase in amplitude until the tree is uprooted. This process is not cancelled by the fact that an oscillating tree represents a rather strongly damped system.

Younger and smaller trees, perhaps up to nine and ten inches in diameter (at the ground) were apparently broken by the wind-force alone, at a height of about five feet; this height is only an approximate average as individual cases differed widely according to the tapering of the stem with height, the friction-conditions over the surrounding surface, the density of the foliage, etc. Where the friction at the ground was great and the foliage relatively thin, the trees were broken by the storm at a rather great height. Near Dublin, New Hampshire, the writer saw relatively thin trees broken by the hurricane of September, 1938, at a height of about 12 feet.

Distribution of destruction--The region of houses that were completely destroyed is more or less restricted to a small coastal strip and generally the degree of destruction decreased remarkably fast inland.

In the forests, small isles of severe destruction alternate with lots where not a twig is broken. Frequently the contours of the ground can be causally connected with these phenomena; apparently, very small undulations of the ground can give rise to an upward deflection of hurricane winds. The destruction was often concentrated on the windward side; but the leeside and also the uppermost parts of the undulation were free of damage.

There was a small grove of pines which before the storm offered the ordinary picture of normal trees standing erect, but after the hurricane a number of them had a slanting position, tipped perhaps 20° to 30° from the vertical. They looked almost exactly like a picture of trees deformed by steady winds. An attentive observer, however, could readily distinguish between these and wind-deformed trees because the crowns were not one sided but were more or less symmetrically developed. As a decisive fact one could note that the ground adjacent to the stems was a little uplifted on the windward side, so not every leaning tree should be considered the result of a strong, prevailing air-current.

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NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 223, 224, 248, 265, 274, 297, 300, and 304)

NOTES

Russian Odyssey--[*I. E. Church*, President of the Section of Hydrology, who was one of those who recently attended the 220th Anniversary of the Russian Academy of Sciences (see page 12, *Transactions*, August, 1945), kept a diary of his trip which it was the Editor's privilege to read. This story is so fraught with interest that Dr. *Church* gave permission to condense it for publication in the *Transactions*.----Editor] Word of the invitation to go to Russia caught Dr. *Church* by surprise, and after a week of uncertainty, during which "shots" were taken, a Soviet plane that was too small arrived, and an appeal was sent to President *Truman* for a plane; the party of sixteen departed early June 10. They went by way of Newfoundland, the Azores, Casa Blanca, Biskra, Tripoli, and Cairo. Over the Nile Valley the sun rose June 12 "as a great red disk, with the pyramids casting shadows like spires." They proceeded early on June 13 over the Suez--"clouds more gossamer than a fairy carpet"--the shifting sands of the desert, the hills of Palestine, Hebron, Bethlehem, Jerusalem, the Dead Sea with its chemical vats, and the crooked Jordan; thence across agricultural Trans-Jordan, across desert sands and Mesopotamia to Teheran. Early on June 14 they were on their way again, this time by Soviet plane to Baku, where the Russian Academy welcomed them at breakfast. He was impressed by the youthfulness and eagerness of the Russians, and by the size of the oil derrick area. Taking off again, they "rode on the tops of the cumulus clouds--the icebergs of the air," with views of the Volga, the Don, and Stalingrad. The party arrived in Moscow on June 14 somewhat ill. Recalling his weeks in the hospital in Moscow in 1936, Dr. *Church* remarks, "Am I allergic to Moscow?" But others were sick, too.

The next day the celebration began, but most of the party were feeling none too well. An elaborate program filled with art and music centered around the "celebration of the close of the war." A great banquet was in store for them. He remarks that *Merrill Bernard* had caught the friendly spirit of the Russians and was a fine messenger of good-will, and that *Bernard* remarked that during the night he was awakened by mass singing and the marching of soldiers returning home from the War through the Red Square. On June 16 they were feeling better. The celebration of the Geophysical Institute started at 1:00 p.m. in the Opera House, with 100 immortals of Russian Science seated on the stage; medals were distributed to these heroes of learning and science. Greetings were read from *Stalin*, *Molotov*, and others, and the main address was by the President of the Academy. The program closed with Tschaikowsky's Overture of 1812, to which the audience arose. The banquet began at 7:00 p.m. and was one of warmth and friendliness. Gousiva Marine Semênovna, a student of languages, was brought in as his interpreter. Much fun was made of Dr. *Church* participating in the toasts without drinking. The older daugher of Marie Curie sat at their table. On June 17 a visit was made to the Kremlin, and he marveled at the many items of historical interest. On June 18 he and others of the party went to sessions of the Academy of Science, and later to the Institute of Geology. At night they were guests at the Opera, to hear Glinka's Ivan Susanin, and Dr. *Church* found at his side the son of an old Canadian friend. On June 19 he went to the country with the Vice-Director of the Institute of Frozen Ground to see a storehouse built of ice, an igloo with arms extendable to any length, storing 50,000 tons of vegetables for as long as two years. Later he went to the Geographic Institute to talk with Professor *Richter* regarding the melting of snow, and there came upon old Stockholm acquaintances. During these visits and sessions, Dr. Church was striving to build up once more the Russian representation in the International Commission of Snow and Glaciers. On June 20 they were entertained at the American Embassy. On June 21 they set forth at 8:30 a.m. to visit the Volga Canal, which extends all the way to the Caspian Sea, with eight days the usual time required to reach Astrakhan. The Canal is three and one-half meters deep, and wide enough for ships. At the point they visited the Germans had made their farthest advance. On June 22 they went to visit the State and Collective Farms. These convinced him of the latent prosperity and stability of Russia. While all land is state-owned, it may be leased. The State Farms are in reality demonstration farms for cattle-breeding, dairying, etc., and provide a wide choice for the Collective Farms. The State Farm they visited comprised about 2500 acres and was exceedingly well kept. The Collective Farm they visited had 650 acres. The members receive a share of the crops according to the number of hours of labor, and may also receive a bonus. They elect their own chairman. Facilities for irrigation are provided. Dr. Church learned that there were 70 happy children under seven years old who were kept in a nursery during the day, while their mothers were at work. They spent June 23 in Art Galleries, and later Dr. Church talked with Professor Valikanof about forecasting runoff from snow, water equivalent, and temperature. Two aviation officers desired advice from him on the removal of snow. Later he went to the Farewell Session of the academy in the former Summer Palace of the Czars. In the evening there was a reception given by the American Ambassador. June 24 was the day of the great peace parade. By 7:00 a.m. "the streets are already filled with singing troops marching to their positions for the peace parade. On the stroke of ten, Stalin and others appeared at the tomb of Lenin in Red Square. Hurrahs passed like a muffled wave down the lines, and Zukhov proclaimed, 'We have driven our conquerors from our land.' This resounded through Red Square and about 50 salvos took up the note. Troops of the Union passed with their banners.....while a central band played and German standards were trailed in the dirt and flung on the ground before the tomb of Lenin.....endless columns of troops, tanks, guns, and mine-removers--it was to me a pageant of war created for man's desire for freedom, an unforgettable day."

Later the party left for Leningrad, and on June 25 they rolled across the region of battle, with devastation and wrecked battle equipment on every hand. They reached Leningrad about noon. He comments, "We must do our utmost to work out plans for closer cooperation in the affairs of science." At night they attended the Swan Lake Ballet by Tschaikowsky--most delicately and expressively portrayed. Next day, with Bernard and others, he went to the Institute of Applied Physics and to the Hydrologic Institute. Snow-cover, maps, water-equivalent, and stream-flow forecasting were matters of discussion. He was amazed to find that the Russians had translated his works. They are maintaining 5,000 stream gaging stations with records going back 140 years. All Leningrad shows the marks of war, with bullet marks and shell holes everywhere. That night was spent at the Symphony Concert. On June 27 they made a trip to Peter's Palace by the Sea, walked in the forest grounds, and went on other sight-seeing excursions. On June 28 he went with his interpreter and Professor Zubov to the Arctic Institute to meet Professor Wiese who had just returned to Leningrad. The ice-forecasting service is complete and continuous. The Arctic Institute plans to send an article for our Transactions, and to have delegates at the next International Meeting in Oslo. The Central Geophysical Laboratory, visited later, was occupied by the Germans and blown up when they retreated; a better observatory is now planned. Kalatin at the Observatory proposed a world snow-year Dr. Church was questioned about snow measurements and forecasting. Later they left Leningrad to return to Moscow.

On the night of June 29, in Moscow, they attended a recitation of an old epic, with singing and dancing, and a piano concerto. The folk dancing and the acrobatic dances were remarkable. June 30 was designated Stalin Day, but Dr. Church found time to visit the Seismologic Institute and heard from Bronchkowski about earthquakes. They also visited the Society on Cultural Relations at the head of which is Maxim Litvinof, former Foreign Commissar. That night there was a banquet at the Kremlin, and Dr. Church was delighted to find that Stalin was a "quiet, unassuming man, silent withall, quite unlike the grand portraits and statues of him." Molotov and the scientists did the talking, but Stalin offered a silent, well-timed toast to the soldiers who provided a rollicking entertainment at the end of the banquet. On Sunday, July 1, he mentions that the other members of the Mission on Hydrometeorology (F. W. Reichelderfer and C.-G. Rossby, who with Merrill Bernard comprised the members of the Hydrometeorological Mission to Russia) had reached Teheran. That night they bid goodbye to their Russian friends.

At 3:00 a.m. July 2 they took off by Russian plane, passed over the Urals without seeing them, and thus into Asia. Later they crossed the Ob River, landed at Omsk for lunch and rest, and took off again. Ice formed on the windows and the flying suits came into use. Novo-Sibirsk was reached at 5:45 p.m., about 12 hours out of Moscow. They moved their watches ahead six hours (12 hours from New York time). This city had increased in population from 90,000 in 1930 to 900,000 in 1945. Early July 4 the plane took off over snow-flecked mountains and reached Yakutska, Outer Mongolia, in five hours. The temperature was 90°, just 10 degrees from the Arctic Circle. They took off over snow-clad mountains and snow-fed streams--"what a place for snow-surveying"--with the characteristic sunset-sunrise of this northern region. They landed at a new airfield, probably Seimchu, early on July 5, then took off over tundra and landed once more on a steel-mat landing strip at Marskof. Thence they passed over mirror lakes and mountains, and the sea appeared before them. Over Bering Strait they crossed the International Date Line and it was July 4 again. They reached Fairbanks at 5:30 p.m., July 4. At 2:30 p.m., July 5, they took off for Edmonton, thence to Regina, arriving in Minneapolis July 6, when the party broke up. Dr. Church arrived in New York by train at 1:00 a.m July 8, a few hours less than four weeks after his start. The Great Jubilee and his trip around the World had ended.

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REMARKS ON CLIMATOLOGY

A. E. Parr

It is obviously impossible to draw any clear and absolute line of demarkation between climatology and meteorology; the two subjects occupy too much ground in common. Until a very few years ago most of us, nevertheless, had a perfectly clear idea of what we meant when we spoke of climatology as a separate and special field of study. We knew it as we know a path we have followed for years, without being able to reduce it to an equation in geographic coordinates--perhaps even without being able to describe it. But still we were able to follow it again and again without any danger of getting lost. Today our path to climatological knowledge has been confused by a number of newly erected road signs all bearing the same name and all pointing in different directions. One might almost suspect that it had been done deliberately, in order to confuse the "invading" sciences which come in search of the knowledge they need for the solution of their own problems.

Before this confusion came about I believe most of us looked upon meteorology as the analysis and climatology as the synthesis of our knowledge of atmospheric events. Meteorology concerned itself with the explanation of the single event or of the individual phenomenon moving through space and time. Climatology dealt with the integration of these events, and of their effects, within fixed areas. The word integration is used with intention. Climate is not simply the sum or mean of the variables we call weather-conditions. It also expresses the normal pattern of variation, both in time, in space, and in the sequence of the variations themselves.

While dynamic meteorology moved forward with great strides, there was a constantly growing need for climatological knowledge which received almost no support and very little attention except from a small minority composed to a large extent of members recruited from other sciences. When the demand finally became too widespread and too insistent to be disregarded, meteorology showed its adaptability and good intentions by giving new names (all containing the word climatology) to a large number of its meteorological activities. Thus it might seem to an outsider as though meteorology were attempting to draw the fair wind blowing for climatology without changing meteorology's own course or taking on any new ports of call.

Most of the subjects which are now discussed under some climatological name or other would, only a few years ago, have been regarded as problems of meteorology pure and simple. What we are witnessing apparently is simply a gradual reclamation of the name Climatology for the entire subject of Meteorology, now that the older name has been found to possess what almost amounts to a popular appeal. But there is little indication that climatology, as we knew it quite recently and as we think of it in the natural sciences, will receive any more than the stepchild's share of attention which is all it has received from the students of the atmosphere since the introduction of dynamic meteorology.

The reasons offered for this avoidance of a difficult but urgently needed branch of research are twofold. One does not know what to do and, besides, it can't be done. While there may be a grain of truth in each of these complaints there is not an adequate excuse for inaction in either.

Whenever a suggestion is made to have meteorologists and climatologists design and initiate a large-scale program of climatological research, the point is immediately raised that one must first find out from the other sciences and technologies what kinds of climatological information is needed, before such a project can be properly planned and carried out. This at first sounds fair and reasonable, but when we try to obtain the specifications from the natural sciences we almost always run into a blank wall. Only in commerce, industry, and engineering does it seem possible to tell exactly what is wanted, and even here only under the simplest circumstances. Unless we are going to accept that nothing significant can be undertaken, except in narrow specific fields, we must conclude, therefore, that there is something wrong about the reasoning which leads us to wait for other sciences to tell us what climatology should do.

At this point it may be useful to consider another philosophical distinction between the meteorological and the climatological approach. By a rough generalization I believe we might define meteorology as the exact-science aspect, and climatology as the natural-science aspect of the study of the atmosphere. Among meteorologists there would seem to be a tendency to deny that anything useful and significant can be accomplished until and unless it can be done with the rigorous precision, completeness, and simplicity of mathematical equations. But to a natural scientist this would be the same as to say that it would be no use surveying the fauna and flora, the soils and rivers of a landscape, until the results can be stated in numerical tables and expressed in mathematical formulae--which means never. The meteorologists tend to forget that the study of the atmosphere is also part of the survey of the landscape, which must always remain in a large and fundamental sense a descriptive and qualitative study, because a landscape is too complex ever to find a total expression within the limited terms of the exact sciences.

Returning to our difficulties in finding out what meteorological information is wanted by others, we now realize that those who can tell us of their needs are generally the people who are able to base their own activities largely on the methods of fairly precise calculation and who are therefore primarily concerned with the relatively exact scientific aspects of meteorology. But for the natural sciences as a whole, including all aspects of pure and applied ecology, public health, anthropology, geology, and many other subjects, it is impossible to become specific about their needs except in very limited and special cases. And the fault, I believe, lies with climatology's failure to do its duty by its own initiative.

If the botanists, zoologists, and geographers had failed to undertake the tremendous task of classifying the animals and plants of the world and surveying their distribution until somebody else told them what plant or animal they wanted to find out about, what would the state and the prospects of economic entomology, the plant industries, agriculture, fisheries, and conservation be today? In fact the economic entomologist would not even be able to say what insect he wanted to find out about because nobody would know what insects were to be found or how to tell them apart. This, I submit, is exactly the quandary in which the natural sciences find themselves today, when they are asked to tell the climatologists what they want, because climatology has not given them the necessary information to go on.

If we are ever going to advance except at a snail's pace the students of the atmosphere must therefore take the initiative for the next step themselves. It seems obvious to me that what we need is a general meso- and micro-climatological survey of our entire country against which the other natural sciences, both pure and applied, can compare the results of their own surveys and observations. This, of course, is where we learn that it can not be done. But the reason we hear that statement is, in my opinion, simply that meteorology, in its preoccupation with the introduction of exact mathematical methods, has almost totally neglected the development of an adequate system of qualitative classification for climatology as a natural science.

I am not a meteorologist so I am quite incompetent to prepare a system of classification myself. But perhaps I can point to some useful parallels in subjects I know a little more about. When we describe a species in zoology, say a species of herring, we first examine all the features of the entire fish. Whenever possible we do it with a couple of dozen or even a couple of hundred specimens. We then give a full account of the entire appearance of the species, in all its details, but from this account we lift out and earmark separately just a very few so-called diagnostic characters. Perhaps a single character will suffice. And from there on all we have to look for is the presence of these few characters in order to record the occurrence of the species in space and in time. Only if we have reason to suspect that we are running into a previously unknown species, which might differ by other characters, do we have to check again with our complete description. Or if we want to refine our observations so as to record them in subspecific or racial terms. And from the features which are not diagnostic of the species but common to many of them, we draw our definitions of a hierarchy of higher and higher systematic groups, which, in reverse, enable us to arrive quickly and easily at the definition of any species we may be looking for. The role of this qualitative system in the natural sciences is in many ways similar to the role of the mathematical system in the sciences which claim to be more exact. In application to any concrete problem your measurements are substituted for the variables in your equation and the specimens for the generalizations of the qualitative definitions of the system.

I do not claim that climatology is entirely without any system of classification. On the contrary there have been some very notable advances made both in this country and elsewhere. But by comparison with the systems already developed in the other natural sciences, and in the exact sciences too, for that matter, the climatological system is still in a most rudimentary state. And this is probably the main reason why any large-scale climatological research project is so quickly declared to be impossible.

Nevertheless, it would seem to a layman that the development of a more adequate system of climatological classification should be a comparatively easy undertaking. Easy enough so that it could be carried out as part of the larger survey in which it would find application, and would not have to be undertaken separately and in advance of the development of greater plans. If, for example, we find that climatic conditions in the deciduous forests of the northeastern United States usually conform to a certain general pattern of diurnal and seasonal variations, this pattern becomes part of the generic description of eastern deciduous forest climates, and a few special measurements at critical times and under the proper conditions are all that will be required in order to determine and to give an account of conditions in any specific forest within the region. Similarly, the length and diagnostic characters of a herring are all we need to have in order to know its other dimensions and characteristics, which can then be derived from the description of the species and the genus. Perhaps the diagnostic characters in climatology may prove to be relative rather than absolute. The information we need may be the difference between a few measurements made in the forest and in the open nearby under certain conditions of observation, rather than, for instance, the summer maximum or winter minimum temperature in the forest itself. If we now extend our comparison to the climatic conditions observed in the evergreen forests we will find that they conform to a different pattern of diurnal and seasonal changes, especially during the winter, but that they also show great similarities with the deciduous forest climates, particularly in the summer. These similarities we can then transfer from the generic descriptions of northeastern deciduous forest climates and northeastern evergreen forest climates to the family definition of northeastern forest climates in general. Each time we establish a higher classification in the hierarchy of our system, after adequate tests, we reduce the need for extensive observations and repetitive descriptions on lower levels. And it would seem particularly true that a determination of the diagnostic characters of the specific types of micro- and meso-climates would so enormously reduce the number of data required that it would bring entirely within the realm of practical possibility the task of making such a climatological survey as I have already suggested.

Reasoning by analogies drawn from a different field of study is always an awkward process and probably the hypothetical illustrations I have tried to suggest may seem very crude to you. But there is nothing crude about a system of classification such as that developed in zoology, which today enables us to identify and tell apart, without any waste of words or needless observations, more than half a million species of insects, in spite of all the individual variations and anomalies to be found in the single specimens. If the students of the atmosphere generally would learn to take a similar systematic attitude towards climatology as a chapter of natural history, using qualitative classifications to reduce the need for quantitative measurements, nothing in the task of making a comprehensive survey of our climates would seem impossible to them today, any more than it seemed impossible for the entomologists to survey our myriad insect life.

The American Museum of Natural History,
New York, New York.

(Manuscript received June 10, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until March 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 224, 248, 265, 274, 297, 300, and 304)

PERSONALIA

Beno Gutenberg of California Institute of Technology has recently been elected an Honorary Member of the Royal Society of New Zealand.

C. S. Gwynne of Iowa State College spent the summer months on a ground-water survey of southern Ontario for the Department of Mines, Province of Ontario.

Leiv Harang of Nordlys Observatoriet, Tromsø, Norway, writes that he has survived the five years of occupation and isolation. It was necessary for them to remove their instruments in 1944 because the Germans were systematically destroying everything in the north part of Norway. The capitulation came before the Observatory was destroyed. Geomagnetic records were maintained without interruption, but ionospheric and much of the auroral work was stopped. He was interned in Germany until the latter part of April 1945, and got back to Norway just after the German surrender.

NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 248, 265, 274, 297, 300, and 304)

PERSONALIA

Richard A. Hertzler has left the Forest Products Laboratory at Madison, Wisconsin, to take charge of the Forest Products Utilization Unit at the Appalachian Forest Experiment Station, Asheville, North Carolina.

W. W. Horner of St. Louis was recently designated as the official nominee for President of the American Society of Civil Engineers.

Arthur L. Howland, who has occupied a war-time post with the Military Geology Unit of the United States Geological Survey, has returned to Northwestern University. He was recently appointed Acting Head of the Department of Geology.

M. King Hubbert of the Shell Oil Company, Houston, Texas, has been made Associate Director of Exploration and Production Research.

Earl Ingerson of the Geophysical Laboratory of the Carnegie Institution of Washington has gone to Brazil on quartz-crystal investigational work.

J. J. Jakosky of Los Angeles, California, was recently elected Vice-President of the Society of Exploration Geophysicists.

Poul Jestersen, biological oceanographer (planktonologist) of Denmark, has written that he was able to continue much of his work during the period of occupation and complete a number of publications. These will be listed in a later issue of the Transactions.

Marshall Kay of Columbia University has received a letter from J. H. F. Umgrove of the Technische Hoogeschool in Delft, Holland, in which he mentions that they have seen no English or American scientific publications since May 1940. He requests reprints of articles relating to geology, paleontology, and geophysics.

G. C. Kennedy, formerly with the United States Geological Survey, has accepted a position with the Naval Research Laboratory in Washington, D. C.

Philip B. King of the United States Geological Survey has recently been elected to resident membership in the Washington Academy of Sciences in recognition of work in stratigraphy and structural geology.

Helmut Landsberg, who has been on meteorological work in Washington in connection with the activities of the Twentieth Air Force, has recently returned to his work in the Department of Meteorology at the University of Chicago.

L. Don Leet of Harvard University was in New Mexico to make observations at the test of the atomic bomb. He is now in Manila to help set up a branch of Office of Scientific Research and Development there.

T. S. Lovering is on leave of absence from the University of Michigan. He is in Utah doing a unique type of field-laboratory research for the United States Geological Survey.

Walter C. Lowdermilk of the United States Soil Conservation Service and Past President of the American Geophysical Union, and Reed Bailey of the United States Forest Service, have recently been at the Volcano Parícutin studying erosion and mud-flow problems.

Hugh E. McKinstry has been appointed Professor of Geology at Harvard University.

Alvin G. McNish of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to geophysics.

Howard A. Meyerhoff of Smith College has recently taken up duties as Executive Secretary of the American Association for the Advancement of Science.

Robert A. Millikan has retired as the head of California Institute of Technology and has been made Vice-President of the Board of Trustees, with opportunity to continue research work.

L. L. Nettleton of Pittsburgh, Pennsylvania, Vice-President of the Section of Tectonophysics, was recently elected editor of Geophysics.

T. B. Nolan has been appointed Assistant Director of the United States Geological Survey.

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DIVERGENCE OF THE HORIZONTAL WIND

Norman R. Beers

Abstract--The divergence of the horizontal wind is investigated from the viewpoint of observational wind-data. It is shown that in many cases in nature the horizontal divergence may be given by the product of wind-speed and the divergence of the unit-vector tangent to the horizontal stream-line. The divergence of this unit-tangent is determined analytically for various plane curves and for curves on a spherical surface. Computational techniques are given and numerical answers obtained for the most interesting cases of elliptical and sinusoidal stream-lines in the plane. The theories are applied numerically to demonstrate that divergence aloft is adequate to overcompensate frictional convergence in cyclones (conversely in anticyclones convergence aloft overcompensates divergence in the frictional layer). It is suggested that the shapes of stream-lines at the 500-mb level (as approximated by isohypses) or at the 20,000-foot level may be used to formulate rules of thumb for forecasting surface pressure-tendencies. It is emphasized throughout that accurate quantitative calculation requires more accurate observations of upper winds, and that the analyst must make a full three-dimensional analysis using data at several upper levels when available.

(1) Introduction and definitions--Let rectangular cartesian coordinates be fixed with origin at the surface of the Earth. Let the x-, y-, and z-axes be directed east, north, and up, respectively. The wind at any time (t) is given by the vector-field $\underline{v} = (u, v, w)$ where u, v, w are component velocities of air-particles along the x-, y-, and z-axes, respectively, and u, v, w are functions of position and time, that is $u = u(x,y,z,t)$, etc. for v and w.

The divergence of any vector-field is defined to be

$$\text{div } v = \nabla . v = (\partial u/\partial x) + (\partial v/\partial y) + (\partial w/\partial z) \ldots\ldots\ldots\ldots (1)$$

where the vector-field $\underline{v}$ may be the wind or any other vector-field. Similarly the divergence of the horizontal wind (the horizontal divergence of the wind) is defined to be

$$\nabla_h . v = \nabla . v_h = (\partial u/\partial x) + (\partial v/\partial y) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

When the divergence is negative it is customary in meteorology to refer to its magnitude as convergence. Thus, for any point in any vector-field, the algebraic sum of divergence and convergence is always zero.

Both divergence and horizontal divergence of any vector-field are scalar functions of position and time; both are invariant with respect to orthogonal transformations and to rigid motions of the axes. These facts permit selection of coordinate frames that are convenient from the aspects of symmetry. At a fixed time the divergence and the horizontal divergence are functions of position alone. Thus if the vector-field $\underline{v}$ is known at time (t), say at the time of the weather-map, the divergence may be determined from the vector-field at that time. Dynamical and physical processes that preceded or may follow in time have no direct bearing on what the divergence is at a fixed time, though both are physically associated with what the divergence formerly was and with what it will be at a later time.

The practical aspect of the above statement is that a weather-map at a fixed time may be used to determine the horizontal divergence of the wind at the time of the map. That is, divergence is correctly associated with stream-lines of the flow, not with isobars or isohypses, or with trajectories as is sometimes attempted. In many cases in nature isobars (or isohypses) and stream-lines are near enough to coincidence so that the one set of curves may be used approximately for the other (in upper-air analysis one usually draws isobars about in the direction of the wind). But only in a steady state can the stream-lines be replaced by trajectories.

Example--Consider the vector fields given by (1) $v = (axt,0,0)$, (2) $v = (ax,0,0)$, and (3) $v = (a,0,0)$. Here a is a constant, x is the distance along the x-axis, and t is time. The divergence of the vector-field is given by at, a, and 0 in the three cases. In words, the divergence here is (1) a function of time and independent of position, (2) constant everywhere and always, and (3) zero identically. Had the velocity contained a power of x in its u-component, the divergence would also have been a function of position.

It is useful to recall EULER'S original concept of divergence. Let Q be the volume of a closed regular surface that contains fluid. Let the closed surface move in such a way that it contains the same mass-element of fluid throughout the motion. Assume that no fissures exist or develop within any such closed surface selected anywhere in a region that contains fluid, that is, let the density (ρ) of the fluid be and remain a continuous function of space and time. Then the product ρQ is a constant throughout the motion and in the usual notation we have $(d/dt)(\rho Q) = 0$ and $[(1/Q)(dQ/dt) + (1/\rho)(d\rho/dt)] = 0$ where the quantity $[(1/Q)(dQ/dt)]$ is called the divergence or the dilatation or expansion at the point considered. From logical principles it follows from its definition that $[(1/Q)(dQ/dt)]$ is independent of the choice of coordinate axes used to describe the motion. When rectangular axes are chosen it is not difficult to show that

$$[(1/Q)(dQ/dt)] = (\partial u/\partial x) + (\partial v/\partial y) + (\partial w/\partial z) = \nabla . v \quad \ldots\ldots\ldots\ldots (3)$$

in the usual notation. The utility of introducing axes is that the divergence is thereby expressed in terms of derivatives of observable quantities, namely the velocities u, v, w. This procedure then permits the magnitude and sign of the divergence to be found when the velocity-field is known; but it is not necessary to understand what is meant by the divergence in a moving fluid.

(2) Importance of horizontal divergence in meteorology--The horizontal divergence of the wind enters into BJERKNES' tendency-equation. Consequently when the quantity can be determined from observations of meteorological elements at some time (t), the equation can be used prognostically to forecast impending pressure tendencies. Fundamentally this has an advantage over the current practice of extrapolating into the future the three-hour (or longer) observed tendencies. For what is ultimately desired in this connection is the pressure-tendency as a function of time so that an integrated value over a finite time-interval can be forecast. This result will be obtained when both divergence and advection effects can be given as functions of time.

So far the difficulties in the procedures here suggested have been that wind observations rarely have been made with sufficient accuracy. This situation is not yet completely satisfactory, but such progress is being made that one may hope for greater useful application of the observations within a short time. It is the responsibility of the dynamic meteorologist to show the necessity for more, and more accurate, observations before, rather than after, he makes a demand that they be taken.

The most usual qualitative application of horizontal divergence is associated with the intuitive notion that divergence implies descending air and resultant clear skies, while horizontal convergence implies ascending air and condensation forms. Recent papers of NEAMTAN [3] and of LOWELL and ROBBINS [2] give thorough discussions of these ideas and show that the intuitive conclusions are correct.

(3) Determination of horizontal divergence--A number of methods are already available for determining the horizontal divergence, at least qualitatively, but no completely adequate method to determine it quantitatively has as yet been devised. Several quite different approaches are possible. Perhaps the simplest in some cases, and certainly the most direct, is to evaluate $[(\partial u/\partial x) + (\partial v/\partial y)]$ graphically from a synoptic map on which are plotted the observed winds, but this method is tedious to apply and the results are often untrustworthy in practice.

Many approaches to horizontal divergence involve dynamical principles. Here winds are computed, or graphically determined, from the isobaric field on a geopotential-surface (or geopotential-field on an isobaric surface). Useful results are obtained from considerations of simple isobaric patterns. Recourse may be had also to the relations between horizontal divergence and vorticity. Finally, some success has met a thermodynamic approach which involves the use of isentropic surfaces.

Qualitative estimates of the horizontal divergence may, of course, be made by almost any method in pronounced cases. Ultimately all methods must reduce to the fundamental concept that $[(\partial u/\partial x) + (\partial v/\partial y)] > 0$ means horizontal divergence while $[(\partial u/\partial x) + (\partial v/\partial y)] < 0$ means horizontal convergence. In the simplest imaginable case, motion in a straight line so that $v = 0$

say, there is horizontal divergence when $(\partial u/\partial x) > 0$, that is, there is horizontal divergence when the velocity increases in the direction of the flow and horizontal convergence when the velocity decreases in the direction of flow.

(4) Horizontal divergence in the friction-layer--Within the friction-layer there is generally a flow of air across isobars in a geopotential-surface from regions of high to regions of low pressure. This flow generally (though not necessarily) leads to divergence from anticyclones and horizontal convergence into cyclones. The physical and dynamical theories of turbulent flow are inadequate to specify the flow in general, but it is not difficult to make quantitative calculations for certain ideal systems.

Consider a case where the wind in a geopotential-surface blows everywhere at an angle α from high to low pressure across straight, parallel isobars. Let the angle α be constant and choose axes so that the x-axis is in the (constant) direction of the wind. Then $\nabla_h . v = (\partial u/\partial x)$ and the horizontal divergence is zero unless the wind-speed varies. If the wind-speed increases as the cyclone is reached, there is horizontal divergence. Conversely there is horizontal convergence if the wind-speed decreases toward the cyclone. The scheme is illustrated in Figure 1.

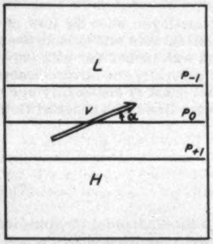

Fig. 1--Cross-isobar wind-flow due to friction

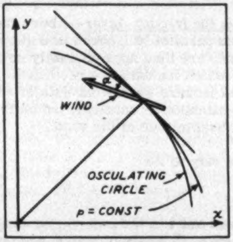

Fig. 2--Cross-isobar wind-flow due to friction

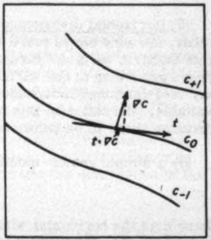

Fig. 3--Isolines of horizontal wind-speed and graphical computation of $t \cdot \nabla c$

A case more nearly resembling what may be found in nature is the following: Let $c = \sqrt{u^2 + v^2}$ be the horizontal wind-speed, and consider a case where c is a function of r alone, and r is the distance from the point for which the horizontal divergence is desired to the center of the osculating circle to the stream-line of flow. Take the origin of axes at the center of the osculating circle. Let the wind blow into the center of the circle at an angle α between the wind and the tangent to the circle. Points on the circle are given by $x = r \cos \theta$ and $y = r \sin \theta$. At the point x, y on the circle the wind is

$$
\begin{aligned}
u &= - c \sin (\theta + \alpha) \\
v &= c \cos (\theta + \alpha)
\end{aligned}
$$

whence by trigonometry

$$
\begin{aligned}
(u/c) &= - (y/r) \cos \alpha - (x/r) \sin \alpha \\
(v/c) &= (x/r) \cos \alpha - (y/r) \sin \alpha
\end{aligned}
$$

The model is shown in Figure 2.

For the case where the ratio (c/r) is constant, α = constant, and adjacent stream-lines have osculating circles that are concentric, one finds by differentiation that

$$\nabla_h . v = - (2c/r) \sin \alpha \quad \ldots\ldots\ldots\ldots \quad (4)$$

For the case where c is constant, α is constant, and adjacent stream-lines have concentric osculating circles,

$$\nabla_h . v = - (c/r) \sin \alpha \quad \ldots\ldots\ldots\ldots \quad (5)$$

Equations (4) and (5) give the divergence at a point, in the neighborhood of which the above conditions are satisfied. If the flow is unsteady so that the conditions are impermanent, then the divergence may be given by some other term later on; all the above is of course to be computed at some fixed time (t) at which the assumptions hold good. The results are in complete agreement with the qualitative statements above that there is frictional divergence from anticyclones and convergence to cyclones in the horizontal.

The angle α in the above equations must be determined by physical considerations or by observation. Its value will generally decrease, going from surface layers (where it may be nearly 90° in intense cyclones) to the top of the friction layer (where it will be zero in the absence of acceleration, but may be positive or negative with acceleration). An average value through the entire friction-layer is probably not in excess of 15°.

If the system considered is simply a circular cyclone with the angle α everywhere constant, and if the motion is steady so that stream-lines and trajectories are coincident curves, both trajectories and stream-lines are given by the logarithmic spiral

$$r = r_0 \exp(-\theta \tan \alpha) \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

(5) Horizontal divergence above the friction-layer--Above the friction-layer when the flow is steady, the wind blows more or less parallel to isobars in a geopotential-surface and to isohypses in an isobaric surface. Stream-lines are then approximately coincident with isobars or with isohypses according to the surface in which the data are recorded. More generally the stream-lines may be determined independently of isobars when wind-data of sufficient quantity and quality are available. Hereafter in this paper attention is concentrated on the stream-lines of horizontal flow, assuming these to be known from observations of the wind.

By a simple vector-identity we may write

$$\nabla_h . v = c \nabla . t + t . \nabla c \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where c is the horizontal wind-speed and t is the unit-vector tangent to the horizontal stream-line. Thus $c^2 = (u^2 + v^2)$ and $t = [(u/c), (v/c), 0]$ where u and v are component velocities along the x- and y-axes, respectively.

Equation (7) breaks the horizontal divergence down into two parts: (1) The wind-speed times the divergence of the unit-vector tangent to the horizontal stream-lines; and (2) the scalar product of the unit-tangent and the gradient of the horizontal wind-speed.

Inspection of upper-air maps shows that the term $t . \nabla c$ is frequently negligible. In other cases of real interest in nature it may, of course, be large. It is useful to examine conditions which are sufficient (not necessary) for the term to be zero.

Neglecting friction the energy-equation is rigorously

$$\frac{d}{dt}\left(\frac{u^2 + v^2 + w^2}{2}\right) + gw + (1/\rho)\, v . \nabla p = 0 \ldots\ldots\ldots\ldots (8)$$

Equation (8) holds good, whether the flow is steady or unsteady, and whether the atmosphere is in barotropic or in baroclinic equilibrium. When the horizontal wind is parallel to the isobars then $[u(\partial p/\partial x) + (v \partial p/\partial y)] = 0$ and equation (8) becomes

$$\frac{d}{dt}\left(\frac{u^2 + v^2 + w^2}{2}\right) + gw + (1/\rho) w (\partial p/\partial z) = 0 \ldots\ldots\ldots (8')$$

When, in addition, the atmosphere is in hydrostatic equilibrium, then $[g\rho + (\partial p/\partial z)] = 0$, and

$$\frac{d}{dt}(u^2 + v^2 + w^2) = 0 \ldots\ldots\ldots\ldots\ldots\ldots (8'')$$

or the speed of an individual parcel of air does not change following the motion.

Consider the case where, in addition to the above restrictions, the vertical velocity independently is constant following the motion (a condition that would occur when uniform winds blow up a warm frontal surface of constant slope). Then $(dw/dt) = 0$, and $(dc/dt) = 0$, where c is the horizontal wind-speed. If, also, the vertical gradient of the horizontal wind-speed is zero, that is, $(\partial c/\partial z) = 0$, then

$$[(\partial c/dt) + u(\partial c/\partial x) + v(\partial c/\partial y)] = 0. \quad \text{or} \quad [(\partial c/\partial t) + t.\nabla c] = 0 \ldots\ldots\ldots\ldots (8''')$$

Finally, if the horizontal wind-speed is steady we have $(\partial c/\partial t) = 0$, and

$$t.\nabla c = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

In summary, the above argument shows that the horizontal divergence of the wind is by equations (7) and (9)

$$\nabla_h . v = c\nabla . t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

in the interesting case where (a) friction and turbulence are negligible, (b) horizontal wind is parallel to isobars in a geopotential-surface, (c) the atmosphere is in hydrostatic equilibrium $[(\partial p/\partial z) = -g\rho)$, (d) the vertical velocity of a parcel is constant following the motion, and (e) the horizontal wind-speed is independent of elevation and of time.

It is not suggested that $t.\nabla c = 0$ in all cases in nature, even where friction is negligible. The model atmosphere in which $t.\nabla c = 0$, so that $\nabla_h.v = c\nabla.t$, is, however, one that permits non-zero vertical velocities, and is consequently of considerable interest in meteorology. In this case it is apparent from equation (10) that the horizontal divergence is given by the product of wind-speed with some function of the "shape" of the isobars.

In all cases equation (7) holds good. The problem of finding the horizontal divergence as a function of position at some synoptic time is then resolved into two parts. One part depends on wind-direction and gradient of wind-speed, and the other on wind-speed and the divergence of the unit-vector tangent to the stream-lines.

(6) Gradient of wind-speed term--The term $t.\nabla c$ can be found graphically by plotting magnitudes of horizontal wind-speed at fixed levels. Lines of equal speed are drawn and the gradient determined in the usual way; direction is plotted accurately after the above isolines are drawn. Then, at any point the horizontal divergence, due to this term, is given by the magnitude of the gradient of horizontal wind times the cosine of the angle between the wind and the vector ∇c. Figure 3 illustrates the procedures.

(7) Divergence of the unit-tangent--The determination of $c\nabla.t$ resolves itself into a study of the "shapes" of the family of horizontal stream-lines. It may be emphasized that neither theoretical considerations nor observations assure that the stream-lines are any particular known plane curves. Meteorology has yet to produce a KEPLER (or a NEWTON) and one is forced to expedients. Thus, any stream-line may be approximated for some purposes by a series of chords and for other purposes by a series of arcs of osculating circles. Finally, any curve may be approximated as closely as we please by a polynomial. But, as will be shown below, the first two approximations are too rough-grained for present purposes and, clearly, the labor of replacing a curve by a polynomial of even the third or fourth degree is too great to recommend in practice.

It is also worth noting that given the same data (a finite number of observations), no two analysts will draw identical stream-lines or isobars; nor will any one analyst draw the same curves for identical data plotted on different map-projections. In fact, the plane curves drawn to fit a set of data on a Mercator projection, say, are not the same plane curves that fit the data when plotted on a polyconic projection.

The best accuracy would no doubt be obtained by plotting and drawing on a hemispherical surface. Then, with enough data, all analysts would draw about the same curves for stream-lines, isobars, etc. But such surfaces are not in current use, and it remains to be seen whether they are desirable in practice. Some attention is given below to curves on spherical surfaces, but it seems adequate in most cases to limit oneself to plane curves (unless of course the region under investigation covers a large solid angle measured at the Earth's center).

It has been remarked elsewhere, and is apparent from inspection of upper-level maps, that isobars, isohypses, etc. "look like" circles, ellipses, hyperbolas, sine-curves, etc., or, of course, combinations of such plane curves. It is, in fact, accepted practice to assume that upper-level isobars sometimes actually are such plane curves and to investigate the consequences of the assumption. This practice is followed below by computing the quantity $c\nabla.t$ for various families of plane curves. The question whether the real isolines in nature can, with sufficient accuracy, be replaced by particular families of plane curves is for statistics to answer. The answer cannot be given by logic or by mathematical formulation at the present time. The mathematical analysis must, however, be relied on to provide theoretical relationships which may be tested by observations.

The writer's experience of about one year, with conclusions drawn from analyses on 10,000-foot and on 500-mb maps, is that the theoretical results given below may be safely applied in practice to indicate qualitatively the regions of pronounced pressure-change at the surface. The type of curve represented by the isolines is deduced in practice by inspection from data analyzed with reasonable care on any map-projection in current meteorological use. It should be emphasized, however, that analysis is necessary at more than one level, since the surface-pressure tendency depends on what occurs at all levels above.

(8) Stream-lines in a plane surface--Suppose the stream-lines of the velocity-field are known in a plane surface. Let the function $f(x,y)$ represent the slope of the tangent to the stream-line at the point (x,y) at some particular instant of time (t). Then at time (t)

$$(dy/dx) = (\dot{y}/\dot{x}) = (v/u) = f(x,y) \ldots\ldots\ldots\ldots (11)$$

in the usual notation, and

$$\left.\begin{aligned} c\nabla.t &= c[\partial(u/c)/(\partial x)] + c[\partial(v/c)/(\partial y)] \\ c\nabla.t &= [c/(1+f^2)^{3/2}][f(\partial f/\partial x) - (\partial f/\partial y)] \\ c\nabla.t &= -[u/(1+f^2)][f(\partial f/\partial x) - (\partial f/\partial y)] \end{aligned}\right\} \ldots\ldots\ldots\ldots (12)$$

where $t = [(u/c),(v/c),0]$ and $c^2 = (u^2 + v^2)$. Equations (11) and (12) hold good for all families of curves when the derivatives exist, but to obtain useful results they must be applied to particular families.

Case I--Let the stream-lines be parallel straight lines. The pertinent equations are then $y = (mx + b)$ and $f = m =$ constant, where the slope (m) is the parameter for one particular set of curves, each curve (straight line) of the set being given by a different value of the intercept b. By differentiation and substitution into equation (12) one finds that (see Figure 4)

$$c\nabla.t = 0 \ldots\ldots\ldots\ldots (13)$$

Case II--Let the stream-lines be straight lines converging to or diverging from a point. Then, with origin chosen where the lines meet and slope (m) as parameter, we have $y = mx$, $f = (y/x)$, and by differentiation and substitution into equation (12)

$$c\nabla.t = \pm[c/(x^2 + y^2)^{1/2}] \ldots\ldots\ldots\ldots (14)$$

where $c\nabla.t$ is positive or negative according as the flow is from or to the origin (see Fig. 5).

Case III--Let the stream-lines be the family of ellipses, all with center at the origin and all with constant eccentricity. Then $[(x^2/a^2) + (y^2/b^2)] = 1$, $f = -(b^2x/a^2y)$, $(a/b) = \epsilon =$ constant $\geqslant 1$, where the ratio of semi-major to semi-minor axis is the parameter for one particular set of ellipses, each ellipse of the set being given by a different length of semi-major (or semi-minor) axis. Differentiation and substitution into equation (12), with some reduction, results in

$$\left.\begin{aligned} c\nabla.t &= [(a^2 - b^2)xu/(a^4y^2 + b^4x^2)] \\ R\nabla.t &= [(\epsilon^2 - 1)\quad {}^2\, m(1 + m^2)^{1/2}/(\epsilon^4m^2 + 1)^{3/2}] \end{aligned}\right\} \ldots\ldots\ldots\ldots (15)$$

where $R = (x^2 + y^2)^{1/2}$ = distance from the origin to a point $P(x,y)$ on the stream-line, $\epsilon = (a/b)$ = ratio of semi-major to semi-minor axis, $m = (y/x) = \tan\delta$, and δ = angle between x-axis and radius-vector from origin to the point $P(x,y)$ on the stream-line.

The dimensionless number $R\nabla.t$ may be computed once for all time for various values of the parameter ϵ and plotted as shown in Figure 6 for $\epsilon = 2$ and $\epsilon = \sqrt{2}$; also shown in Figure 6 by a dashed line is the stream-line for $\epsilon = 2$ in the first quadrant. The quantity $c\nabla.t$ is found from the identity

$$c\nabla.t = (c/R)(R\nabla.t) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

after the horizontal wind-speed $c=(u^2 + v^2)^{1/2}$, distance R and $R\nabla.t$ are obtained from the synoptic map and Figure 6 (or a similar figure for values of the parameter appropriate to the stream-lines).

A glance at the identity $\nabla.v = -\nabla.(-v)$ shows that the sign of $\nabla.t$ is reversed when the direction of flow around the ellipse is reversed. By reference to the first of equations (15) and by noting the symmetry involved, it may be seen that $\nabla.t$ is positive or negative in the four quadrants of the ellipse as indicated in Figure 7 for cyclones and for anticyclones. It will be noted that $\nabla.t = 0$ on the axes of the ellipses. From Figure 6 it is apparent that for $\epsilon \gg 1$, $R\nabla.t$ has pronounced extremes close to the major axis.

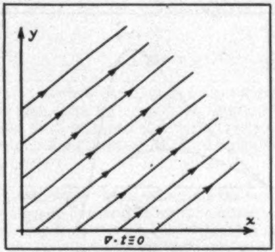

Fig. 4--$c\nabla\cdot t$ with straight, parallel stream-lines

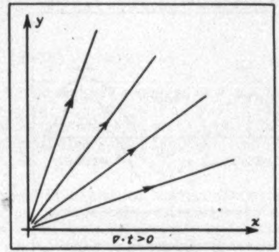

Fig. 5--$c\nabla\cdot t$ with straight, diverging stream-lines

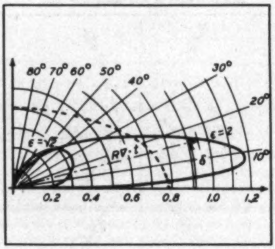

Fig. 6--$R\nabla\cdot t$ for elliptical stream-lines when $\epsilon = 2$ and $\epsilon = \sqrt{2}$

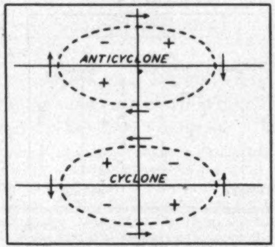

Fig. 7--Sign of $c\nabla\cdot t$ in cyclone and anticyclone with elliptical stream-lines in Northern Hemisphere

It is important to note that $\nabla.t = 0$ everywhere in the plane when $\epsilon = 1$ (that is, when a = b). Thus in the case where the ellipses have degenerated into circles, the complete expression for horizontal divergence of the wind reduces to $\nabla_h.v = t.\nabla c$, that is, the horizontal divergence of the wind is zero when stream-lines are circles unless there is a non-zero component of the gradient of wind-speed in the direction of the wind.

Case IV--Let the stream-lines be the family of sine-curves, $(y - y_0) = A \sin(2\pi x/L)$ and $f = (2\pi A/L)\cos(2\pi x/L)$ where A is the amplitude and L the wave-length. A and L are separately constant for one particular set of sine-curves, each curve being given by a different value of y_0.

Differentiation and substitution into equation (12) result in

$$L\nabla.t = (8\pi^3/\epsilon^2)\sin(2\pi x/L)\cos(2\pi x/L) \Big/ [1+(4\pi^2/\epsilon^2)\cos^2(2\pi x/L)]^{3/2} \quad \ldots\ldots (17)$$

where $\epsilon = (L/A)$, and x is the distance along the major axis. The appearance of the family of curves and the notation are clarified in Figure 8.

The dimensionless number $L\nabla.t$ may be computed once for all time for various values of the parameter ϵ and plotted as shown in Figure 9 for $\epsilon = 4$ and $\epsilon = 10$. Values will repeat, except for sign, in intervals of a quarter wave-length. The sign of $\nabla.t$ is shown in Figure 10 for a representative stream-line. It will be noted that $\nabla.t = 0$ at the wedge- and the trough-lines and half-way between, and for the values of ϵ not too large has pronounced extremes close to the wedge- and trough-lines.

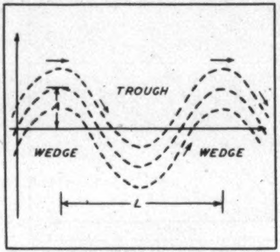

Fig. 8--Sinusoidal stream-lines for $\epsilon = (L/A) = 4$

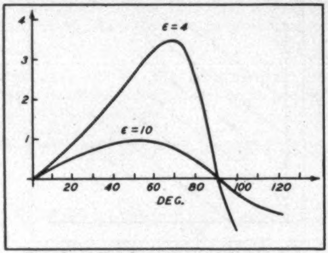

Fig. 9--$L\nabla\cdot t$ for sinusoidal stream-lines when $\epsilon = 4$ and $\epsilon = 10$

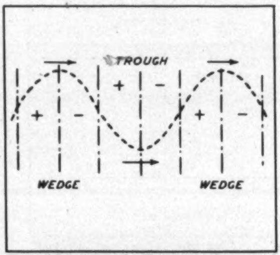

Fig. 10--Sign of $c\nabla\cdot t$ in wedges and troughs with sinusoidal stream-lines

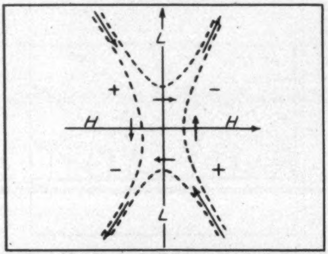

Fig. 11--Sign of $c\nabla\cdot t$ with hyperbolic stream-lines in Northern Hemisphere

The quantity $c\nabla.t$ is found from the identity

$$c\nabla.t \equiv (c/L)(L\nabla.t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

after the horizontal wind-speed $c = (u^2 + v^2)^{1/2}$, and wave-length L and $L\nabla.t$ are obtained from the synoptic map and Figure 9 (or a similar figure for values of ϵ appropriate to the stream-lines).

Case V--Similarly for the hyperbolas $[(x^2/a^2) - (y^2/b^2)] = 1$, $f = (b^2x/a^2y)$, $(a/b) = \text{constant}$, one finds

$$c\nabla.t = -[(a^2+b^2)\,b^2xu/(a^4y^2+b^4x^2)] \quad \ldots\ldots\ldots\ldots\ldots (19)$$

The signs of $c\nabla.t$ are shown in Figure 11. Here, also, one may associate $c\nabla.t$ with the product of a reciprocal length and a dimensionless number as in equation (16) for the ellipse.

(9) Stream-lines in a spherical surface--In terms of spherical coordinates we have for the three-dimensional divergence

$$\text{div } v = (1/r \cos\phi)(\partial u/\partial\theta) + (1/r)(\partial v/\partial\phi) - (v \tan\phi/r) + (2w/r) + (\partial w/\partial r) \ldots . (20)$$

where r is distance from the center of the sphere, θ is longitude, and ϕ is latitude. East, north, and up are in the directions of increasing θ, ϕ, and r, respectively, and the velocities along coordinate axes are u, v, w. If we write, as before, $t = [(u/c), (v/c), 0]$ and $c^2 = (u^2 + v^2)$, then

$$\text{div } v = t.\nabla c + (c/r \cos\phi)[\partial(u/c)/\partial\theta] + (c/r)[\partial(v/c)/\partial\phi] = (v \tan\phi)/r + (2w/r) + (\partial w/\partial r) \ldots . (21)$$

or

$$\text{div } v = t.\nabla c + c\nabla.t + (2w/r) + (\partial w/\partial r) \ldots\ldots\ldots\ldots . (22)$$

Case I--Let the stream-lines be resultant from wind that has south and east components separately constant; then $[\partial(u/c)/\partial\theta] = [\partial(v/c)/\partial\phi] = 0$, $\nabla c = 0$, and $\nabla_h.v = c\nabla.t = -(v/r) \tan\phi$. This case is seen to correspond closely to the case in plane flow where the stream-lines converge from, or to, a point. Here north wind ($v<0$) implies horizontal divergence, and south wind ($v>0$) convergence.

Case II--Let the stream-lines be the space-curves on a spherical surface (for example, a spherical surface concentric with the almost spherical surface that is coincident with mean sea-level) resulting from the intersection of the radius-vector from the sphere's center to points on plane concentric ellipses with constant eccentricities, when the plane containing the ellipses is tangent to the spherical surface. Select coordinates so that the angle ϕ is equal $\pi/2$ when the radius-vector passes through the center of the ellipses. Then it can be shown that

$$c\nabla.t = \frac{-uf[1 + (1+f^2)\sin^2\phi + [(\epsilon^2 - 1)/K_1^2]\cos 2\theta \cos\phi]}{a(1+f^2)\cos\phi \sin\phi} \ldots\ldots . (24)$$

where $f = (v/u) = (\epsilon^2 - 1)\sin\theta \cos\theta/K_1(\epsilon^2 \sin^2\theta + \cos^2\theta)^{1/2}$, $\tan\phi = (1/K_1)(\epsilon^2 \sin^2\theta + \cos^2\theta)^{1/2}$ $K_1 = (\alpha/a)$, $K_2 = (\beta/a)$, $\epsilon = (K_1/K_2) = \text{constant} \geqslant 1$, α = semi-major axis of the plane ellipses, β = semi-minor axis of the plane ellipses, u = velocity in direction of increasing θ, a = radius of the spherical surface (for example, Earth's radius), θ = "latitude," and ϕ = "longitude." In the above equations the angles θ and ϕ are zero and $(\pi/2)$, respectively, when the point considered is the origin of the family of plane ellipses (and origin is at center of ellipse in the plane). This selection of the axes is of course made for convenience. It may be demonstrated for the case considered that the divergence is invariant with respect to the rotation of the axes, but the labor involved is considerable and unnecessary since one has the general theorem from vector-analysis that divergence is invariant under such transformations.

If the ellipses in the plane degenerate into circles then the "projected ellipses" are also circles. Then $\alpha = \beta$, $f = 0$, and $c\nabla.t = 0$. If $\alpha \gg \beta$, $\epsilon \rightarrow \infty$, and then $c\nabla.t = -(v \tan\phi)/a$ for ($\sin 2\theta \neq 0$). These limiting results agree with those found above for stream-lines in the plane, as of course they must. It is especially noted that circular stream-lines always have $c\nabla.t = 0$. The intermediate cases when ϵ is finite are not without interest, but further equations are not given here since numerical computation from equation (24) indicates that for practical work the situation seems to be adequately handled by the simpler elliptical stream-lines in a plane surface. (As before remarked, the spherical surfaces must be considered when the region under investigation covers a large solid angle measured from the Earth's center.)

Case III--Let the stream-lines be given by $\phi = (\phi_0 + \Delta\phi \cos N\theta)$ where ϕ_0, $\Delta\phi$, and N are constants. These stream-lines are distorted sine-curves in a spherical surface where ϕ is longitude and θ is latitude. Again the orientation of the axes is chosen (as is permissible without loss of generality) so that simplicity is attained. Here the orientation is set so that the "sine-curves" cross and recross parallels of latitude, where "latitude" means only the sequence of small circles given by the angle ϕ = constant. These circles may or may not coincide with the latitude-circles on the Earth. With the above stream-lines it is found that

$$c\nabla.t = (v^3/ac^2)[(\cos N\theta/\Delta\phi \sin^2 N\theta) - \tan\phi] \ldots\ldots\ldots . (25)$$

Numerical computation from this equation again shows that it is unnecessary to proceed from the simpler sine-curves on a plane surface to this result, unless the solid angle measured from the Earth's center and enclosing the region under consideration is large.

(10) Notes on the determination of the sign of $c\nabla.t$--From inspection of all the Figures illustrating the above cases for stream-lines in the plane for ellipses, hyperbolas, and sine-curves, it will be seen that $c\nabla.t$ is positive when the curvature of the stream-line increases following the wind, and negative when it decreases. Experience indicates that these statements, mathematically rigorous for the curves under discussion, may be used as rules of thumb to determine whether divergence or convergence exists at a level in any selected region on an upper-level synoptic map. It is not implied that there is always such a relation between the divergence of the unit-tangent and the rate of change of curvature of a plane curve. In fact one sees from the case of diverging straight lines that here curvature is constant, but $c\nabla.t$ may be either positive or negative.

(11) Variation of horizontal divergence with altitude--BJERKNES has shown that the horizontal divergence must vary with altitude above a point (x,y) if a surface system is to deepen or fill. In fact, horizontal divergence will nearly always change with elevation, even when the surface pressure is about constant. These facts are intuitively apparent from observation of several upper-level maps drawn for the same synoptic time. For, as is well known, troughs, wedges, etc. above are almost invariably displaced from their corresponding positions below. Similarly, warm and cold, moist or dry, regions or tongues are displaced in the horizontal plane as one goes aloft. When such displacement is absent, conditions are generally quasi-stationary at the surface.

It follows immediately that only by a thorough three-dimensional analysis can one hope to obtain a full understanding of what is present in the atmosphere at some particular synoptic time. It is reasonable to suggest further that the best forecast of what will occur in the future must be based on just such an analysis, that is, an analysis over large horizontal areas at several levels at least (surface and aloft).

(12) Surface pressure-tendencies--The pressure-tendency at the surface of the Earth is given by BJERKNES' tendency-equation to be

$$(\partial p/\partial t)_{z=0} = -\int_0^\infty g\nabla_h.\rho v dz = -\int_0^\infty g\rho\nabla_h.vz - \int_0^\infty g v_h.\nabla\rho dz \quad \ldots\ldots\ldots\ldots (26)$$

where the first and second terms on the right-hand side of the equation are called the divergence-term and the advection-term, respectively. Any investigation of the surface tendency which may hope to take care of all cases in nature must take both terms into account. This may be done by considering them separately (as has been done here), or by considering the divergence of mass (that is, $\nabla_h.\rho v$) as in a recent paper by BJERKNES and HOLMBOE [see 1 of "References" at end of paper].

The advection-term has been investigated by numerous writers [see recent papers of PETTERSSEN]. The divergence-term is too frequently neglected in practice, primarily because it is difficult to handle by accepted and known techniques. The approach of BJERKNES and HOLMBOE is dynamic in nature, being associated with the equations of motion and isobars or isohypses on upper-level maps. The approach suggested here is essentially kinematic, with evaluation to be accomplished from observations of stream-line patterns deduced from actual wind-data (and until wind-observations are more numerous and more accurate also from the winds deduced from isobaric or isohyptic patterns).

PETTERSSEN transforms the advection-term as in equation (27).

$$\int_0^\infty g v_h.\nabla\rho dz = \bar{v}_h.\nabla \int_0^\infty g\rho\, dz = \bar{v}_h.\nabla p_o. \quad \ldots\ldots\ldots\ldots (27)$$

where $\bar{v}_h$ is a mean horizontal wind through the vertical, and $-\nabla p_o$ the pressure-gradient at sea-level.

The divergence-term may similarly be transformed as in equation (28)

$$\int_0^\infty g\rho\nabla_h.v dz = \overline{\nabla_h.v}\, p_o \quad \ldots\ldots\ldots\ldots (28)$$

where $\overline{\nabla_h.v}$ is a mean value of the horizontal divergence of the wind through the vertical, and $p_o \doteq$ 1,000 mb, the pressure at sea-level.

The question immediately arises. how may $\overline{v_h}$ and $\overline{\nabla_h \cdot v}$ be determined from observational data. If these quantities are known it is a comparatively simple matter to find $\overline{v_h} \cdot \nabla p_0$ and $\overline{\nabla_h \cdot v}\, p_0$ from a sea-level map, and thus obtain the surface pressure-tendency. It is found in practice that both these terms may be obtained with sufficient qualitative accuracy to be useful in forecasting purposes by performing fairly rough numerical integrations to find the mean wind and the mean horizontal divergence.

Quantitative calculations of surface pressure-tendency would require accurate integration of both terms on the right-hand side of equation (26), but estimates may be made in many cases by comparing the present situation with past tendencies observed. In other words, it is feasible generally to state that the tendency will increase, remain constant, or decrease, and (with fair accuracy) to estimate how much the tendency will change. This type of procedure thus invokes "acceleration," or tendencies of the tendencies, and provides information for better forecasts.

The following general qualitative statements may be given, after consideration of horizontal divergence and advection at all levels (including of course the friction-layer): (a) Strong horizontal divergence and/or advection of warm or moist air at some upper levels is necessary and sufficient for a cyclone to deepen and, conversely, horizontal convergence and/or advection of cold air above a cyclone will cause it to fill; (b) strong horizontal convergence and/or advection of cold air at some upper levels is necessary and sufficient for an anticylone to intensify and, conversely, horizontal divergence and/or advection of warm air above an anticyclone at all levels will cause it to decrease in intensity.

As corollaries of the above statements, and in agreement with observations on 500-mb maps, the following rules of thumb may be given; (a) When strong convergence exists at 500 mb over an anticyclone at the ground and when warm air is being advected at and below 500 mb, the anticyclone at the ground becomes "dynamic;" (b) when strong convergence exists at 500 mb over an anticyclone at the ground and when cold air is being advected at and below 500 mb, the anticyclone at the ground moves rapidly toward the region below which convergence at 500 mb is a maximum; (c) when strong divergence exists at 500 mb over the warm frontal surface of a surface cyclone and warm moist air is being advected at and below 500 mb, the cyclone will deepen rapidly and move toward the region below which the horizontal divergence at 500 mb is a maximum; (d) when weak horizontal divergence exists at 500 mb or when there is horizontal convergence over the warm frontal surface of a surface cyclone, the cyclone will fill rapidly and tend to remain stationary.

(13) Condensation forms--As was remarked in Section 2, horizontal divergence implies descending air while horizontal convergence implies ascending air. These facts have been intuitively known for many years and are commonly used to explain the low and middle clouds and even precipitation when surface isobars are curved cyclonically (where there is frictional horizontal convergence), and the frequent clear skies found when surface isobars are curved anticyclonically (where there is frictional horizontal divergence). The mere fact of cyclonic or anticyclonic isobars at the surface or aloft does not however imply either convergence or divergence above the friction-layer. Consequently high cloudiness can be accounted for, not by isobaric shapes at the surface, but only by the flow-patterns aloft with consequent convergence and/or, of course, by frontal surfaces.

As a working hypothesis it may be assumed that wide-scale cloudiness implies wide-scale convergence and conversely. It is at least certain that cloudiness cannot persist in the descending air which we associate with divergence. Similarly absence of condensation-forms implies either completely dry air or wide-scale divergence. The type of cloudiness resultant from convergence depends upon the convective stability of the layers concerned in the lifting process. Thus stable air produces stratiform while unstable air produces cumiliform clouds on being lifted. When different levels show different magnitudes of horizontal divergence or convergence it also follows that cloudiness will exist in layers or sheets. Such stratification into sheets is a common enough occurrence according to pilots.

(14) Numerical examples--A glance at a surface weather-map, which shows a deep and deepening cyclone, shows that the surface winds nearly always blow into the low. This condition produces great convergence. On assuming the case for which equation (4) applies, with an average α of 15°, wind-speed of 30 knots (average up to the top of the friction-layer), radius of curvature of isobars 180 nautical miles, and the friction-layer to be 100 mb thick, we have from equation (28) that the contribution to surface tendency of this frictional convergence is

$$(\partial p/\partial t)_0 = 100(c/r)\sin\alpha = (30 \times 0.26 \times 100)/180 \text{ mb per hour} \doteq 12 \text{ mb per 3 hours} \ldots (29)$$

This amount of plus tendency must be overcompensated by advection and divergence aloft in order that the cyclone not fill rapidly.

The effects of advection aloft cannot, of course, be neglected in any actual case in nature. Yet the air being advected over a warm frontal surface is more or less homogeneous in the horizontal so that the main contribution to the deepening of a cyclone is probably, in most cases, divergence. That these theoretical results provide sufficient magnitude of the divergence, even when the term $t.\nabla c$ is zero, to result in such deepening follows from equations (15) and (17), for example.

Take the case of elliptical stream-lines and apply equation (15). Let the ratio of the ellipse's axes be $\epsilon = \sqrt{2}$. At a point 500 nautical miles distant from the center of the ellipse where the wind-speed is an assumed 30 knots, and at an angle of 12° measured from the major-axis of the ellipse, one finds, by calculation or from the plot in Figure 6, that

$$c\nabla.t = -(30 \times 0.3)/500 \text{ hour}^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

If this amount of divergence persists as an average through a thickness of 500-mb its contribution to the surface tendency is by equation (28)

$$(\partial p/\partial t)_0 = -27 \text{ mb per 3 hours} \quad \ldots\ldots\ldots\ldots\ldots \quad (31)$$

If such a layer of divergent flow lies above the layer of frictional convergence for which equation (29) applies, the net surface pressure-tendency is a 15-mb fall in three hours. Such large tendencies are not uncommon in hurricanes, and are of the order of magnitude of tendencies observed in a "northeaster" in the eastern United States, December 12, 1944. When the eccentricity of the ellipse, or when the wind-speed, is greater, or when the layer through which the divergence persists is thicker, the contribution of the divergence term is even larger. Similarly large tendencies are found by computation from equation (17) or by reference to the plot of Figure 9 for sinusoidal stream-lines.

(15) Synoptic examples--Synoptic examples cannot be given with complete satisfaction because the present upper-level and surface maps as drawn in the United States are not synoptic. Qualitative correlation is, however, generally excellent, especially in pronounced cases, and two such cases are listed below. Maps are not reproduced here because the cases described are recent enough and significant enough so that analyses generally available show the desired items clearly.

Case I: Northeaster of December 12, 1944--United States Weather Bureau map of 02^h30^m shows falling barometers of about 13 mb per 3 hours; 10,000-foot and 500 mb (or 20,000-foot) maps show pronounced elliptical and sinusoidal stream-line patterns implying strong horizontal divergence over the regions where barometers fell most rapidly.

Case II: Dynamic anticyclone of November 30 to December 6, 1944--United States Weather Bureau surface maps show a dynamic anticyclone over the entire eastern United States; 500 mb, 700 mb, and differential-analysis maps for 00^h00^m November 30, 1944, show pronounced convergence aloft over the region where the anticyclone generated. The differential analysis showed marked advection of warm air between 700 and 500 mb.

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A NEW DETERMINATION OF EVE'S CONSTANT

Victor F. Hess and Eva Balling

Abstract--A new determination of the value of EVE'S constant, which employed three ionization-chambers of various sizes having area-volume ratios of 0.249, 0.348, and 0.504, respectively, is described. Applying necessary corrections and extrapolating to zero area-volume ratio, a value of EVE'S constant of 4.63×10^9 ion-pairs per cc per gm radium in air at NTP is deduced.

The portable ionization-meter designed by O. H. GISH and K. L. SHERMAN of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, has been and is still being used by VICTOR F. HESS for the study of the ionization of the atmosphere. It consists of three cylindrical ionization-chambers made of 2.5-mm brass which can be used alternatively and even simultaneously in connection with a well-shielded LINDEMANN electrometer and a panel-box containing a precision-voltmeter, batteries, and switches. The volumes of these three vessels are 13,176, 4,888, and 1,645 cc, respectively. They are geometrically similar, having a ratio of height to radius of 4 to 1.

In order to calibrate these cylinders in terms of radium it is customary to measure the ionization (q) produced in each chamber by the hard gamma-radiation of RaC from a calibrated radium-preparation, shielded with at least six mm of lead in order to exclude the softer gamma rays from RaB.

If the distance (r) between the radium-tube and the center of the ionization-vessel is chosen large enough (as compared with the size of the vessel), the ionization is given by

$$q = K(m/r^2)\, e^{-(\mu d_1 + \lambda d_2)}$$

where m is the amount of radium in grams, μ and λ are the absorption-coefficients of the gamma rays of RaC in lead and in air, respectively, and d_1, d_2 are the thickness of lead and of the air-layer between the apparatus and the radium-tube, respectively.

EVE'S constant (K) therefore denotes the number of pairs of ions produced per cc per second by one gram of radium (computed for unit-distance and for negligible absorption) in the gas with which the chamber is filled.

For studies of atmospheric electricity it is more important to know the value of EVE'S constant for the free atmosphere, that is, to eliminate the additional ionization by the soft secondary rays produced in the walls of the vessel.

A. S. EVE [see 1 of "References" at end of paper] used for this purpose ionization-chambers made of aluminum foil or of tissue paper. G. ISING [2] and E. WALLES [3] tried the use of large soap-bubbles as ionization-chambers. EVE arrived at a final value of $K = 4.0 \times 10^9$ in air in 1914, but neither pressure nor temperature of the air was given. In a letter to VICTOR F. HESS in 1930 he supplied the necessary data, at least approximately, and with these the reduction to normal temperature and pressure (NTP) gave 4.26×10^9 for the value of K in air at NTP.

The most extensive study of the absolute value of EVE'S constant in air was carried out by A. REITZ [4] in the laboratory of V. F. HESS in 1930. Excluding all wall-effects and secondaries from the vicinity of the apparatus he arrived at the value $K = 4.30 \times 10^9$ for air at 0°C and 760-mm pressure.

The set of geometrically similar brass vessels mentioned above offers a new and quite independent way of determining the constant K. If we determine experimentally the values of EVE'S constant in the three brass vessels individually, we get values which increase with the increase of the relative size of the inner surface (A) with respect to the volume (W) from the large to the small chambers. Thus, plotting the experimental values of K versus (A/W) for each vessel we can extrapolate to $(A/W) = 0$, which would correspond to a vessel of infinite dimensions, that is a vessel where the walls are so far apart that the secondary radiation from the walls becomes negligible as compared with the true volume-ionization.

Preliminary experiments showed that this method gave feasible results. The individual values for the three chambers, K_1, K_2, K_3, for EVE'S constant plotted against the respective ratios of surface to volume (A/W) for each vessel lay approximately on a straight line.

The final experiments were carried out with a small radium-tube (2.278 mg Ra) at three distances (6, 8, and 12 feet) from the chambers. The radium-tube was shielded with 1.52 cm of lead. The absorption-coefficient used was 0.531cm^{-1}(in lead). The absorption in 6, 8, or 12 feet of air is very small, but we corrected for it (six feet of air absorb 0.7 per cent of the gamma radiation).

The ionization-chambers were filled with dry nitrogen (767.7-mm pressure at 20°C) after filtering it through cotton. The final values of K were reduced to air and to NTP.

In order to avoid the influence of scattered radiation from the walls of the room, the experiments were performed in the middle of a 30- by 30-foot laboratory room on the top floor of the Physics Laboratory of Fordham University. One set of experiments was carried out in the open air (this set is marked with an "a" in Table 1). No difference between the values of K indoors and outdoors was noticed. The natural ionization (due to cosmic rays and local radiation) was small (8 to 9 I) and was always subtracted from the readings.

Table 1 gives the numerical results of 24 determinations at three distances and with the three chambers. The results are plotted in Figure 1. As it is seen from Table 1, the mean values of K for each individual chamber at distances of 6, 8, and 12 feet, are in good agreement and this indicates that the inverse-square law is verified within the limits of experimental error.

Table 1--EVE'S constant(K) in nitrogen in ionization-chambers of various sizes (K given in 10^9 ion-pairs per cc per gm radium)

Distance of source	Large chamber (A/W) = 0.249	Medium chamber (A/W) = 0.348	Small chamber (A/W) = 0.504
feet			
6	4.71	4.89	5.05
	4.79	4.83	5.22
	4.74	4.67	4.94
Means,	4.75	4.80	5.07
8	4.74	4.82	5.06
	4.92	4.87	5.26
	4.79	4.58	5.03
Means,	4.81	4.75	5.12
12	4.83[a]	4.80[a]	5.13[a]
	4.74	4.64	5.00
Means,	4.78	4.72	5.07
General means,	4.78	4.76	5.08
Mean extrapolated to (A/W) = 0, 4.33×10^9			

[a] Measurement conducted out of doors.

Comparison of the horizontal row of figures shows very clearly the increase of K from the large to the small chamber (see also the slope of the line in Figure 1).

The mean values at all distances for each chamber extrapolated for (A/W) = 0 (infinitely large chamber) gives $K = 4.33 \times 10^9$. This, however, is not the final value. Several corrections have to be applied, namely: (1) Reduction from 20°C, 767.7 mm to NTP by multiplying by 1.062; (2) reduction from nitrogen (density 1.250×10^{-3}) to air (1.293×10^{-3}) by multiplying by 1.034 (see reference [5]); (3) correction on account of absorption of gamma rays in the brass wall of the ionization-chambers by multiplying by 1.097; and (4) correction on account of the interior scattering of gamma rays and production of secondaries from the top and bottom of the chambers. This

influence is not entirely eliminated by the extrapolation to (A/W) = 0; even in the largest chambers the relative effect of this scattered radiation will be much the same as in the smallest one because the dimension of the scattering area for primaries coming at a very small angle with the surface increases almost linearly with the diameter of the chamber. According to A. REITZ [4] this "scattering-correction" for top and bottom of each vessel is 1.125 for aluminum. For brass the figure may be slightly higher. For this reduction we have to divide our value by 1.125, using REITZ' correction.

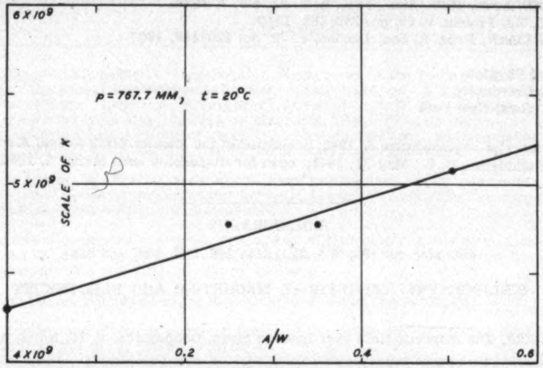

Fig. 1--Value of Eve's constant (K) in nitrogen as a function of size of the ionization-chamber (ratio of surface to volume = A/W)

Therefore, summing up all these corrections, we obtain for EVE'S constant in air at 0° and 760-mm pressure

$$K = 4.33 \times 10^9 \times \left(\frac{1.062 \times 1.034 \times 1.097}{1.125}\right) = 4.63 \times 10^9$$

The accuracy of this value depends upon (a) the calibration of the radium preparation which is probably accurate within ±0.5 per cent, (b) the determinations of the sensitivity of the electrometer [error estimated ±0.5 per cent], (c) the determinations of the capacitance of the three chambers [these were carried out by K. L. SHERMAN with two methods and their accuracy is estimated as ±1 per cent].

Adding to these errors the other possible uncertainties of observations (including the measurements of the distances) we conclude that our final value will be correct within ± 3 per cent.

It is perhaps not surprising that our extrapolation gives a value K which is considerably higher than the ones reported by A. S. EVE and by A. REITZ. Linear extrapolation from three points (see Fig. 1) always involves a certain risk and it is quite possible that the part of the trace on the graph between (A/W) = 0.249 (large chamber) and (A/W) = 0 is too high. We must not forget that the range of the secondary electrons knocked out from the inner surface of the chambers by the hard gamma-rays of RaC is of the order of 20 to 30 cm in air [see 4, p. 274]. Therefore some of them traverse the whole volume of even the largest chamber used by us. In order to be sure about the initial slope of the line it would be necessary to have a fourth chamber available with still larger dimensions.

The relation between the size of the ionization-chamber and the value of EVE'S constant, well established by the experiments described above, will be of great value in deducing the radium-content of rocks from ionization-experiments.

We wish to express our thanks to Dr. J. A. FLEMING, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, for placing the facilities of that laboratory at our disposal, and also to the American Philosophical Society for a grant awarded to the senior

author.

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METEOROLOGICAL INFLUENCES UPON THE RADON-CONTENT OF SOIL-GAS

Edward M. Kovach

Abstract--This paper is a continuation of one given at the Twenty-Fifth Annual Meeting of the American Geophysical Union, in June, 1944, on "A study of the radon-content of soil-gas" [see 1 of "References" at end of paper]. The present paper covers the period from May 17, 1944, to March 25, 1945. Its main purpose is to consider the meteorological influences upon the radon-content, such as barometric-pressure changes, wind-velocity effects, and temperature-variations.

Four depths, 25, 75, 150, and 200 cm, were investigated. In the course of 177 days of actual investigation during this period, covering 642 individual readings, the radon-content of the soil-gas was measured.

Ionization-chambers connected with a Wulf bifilar-electrometer were used, and the amount of radon was calculated in (curie/cc) $\times 10^{-14}$, after calibrating the apparatus by means of a standard solution of radium.

From the results obtained the following conclusions can be drawn:

(1) Dry ground produces constant values of the radon-content at each depth and shows an increase of the content with depth.
(2) A long period of snow-and-ice-coverage of the ground causes all pipes to approach the same value. Frozen ground gives the highest values for the year.
(3) Barometric pressure causes, at least to a depth of 200 cm, a variation such that an increasing pressure tends to decrease the radon-content, while a decreasing pressure produces an increase in radon-content. This effect is most pronounced at the 25- and 75-cm levels.
(4) A high wind-velocity over a number of hours will noticeably reduce the radon-content in the top layers of the ground.
(5) Ground-temperature changes have apparently no great effect upon the radon-content of soil-gas.

Scope of present study--This paper is a report of an investigation carried out at Fordham University upon the suggestion and under the direction of VICTOR F. HESS on the study of the radon-content of soil-gas. The results of the observations in the first three-month period have been given at the meeting of the American Geophysical Union in Washington in June, 1944, and have been published in its Transactions [1]. Our present investigation extends from May 17, 1944, to March 25, 1945. While the previous paper was concerned mostly with the effects of the variable ground-conditions upon the radon-content, the main purpose of this report is to consider the meteorological influences, such as barometric-pressure changes, wind-velocity effects, and temperature-variations, which could only be established after a long period of observation.

Résumé of the apparatus set-up at Fordham University--About 75 feet west from the Physics Building, on a plot of lawn-covered ground, three one-half-inch gas-pipes of lengths 25, 75, and 150 cm were lowered into holes in the ground of corresponding depths. The pipes were about 32 cm apart. This insured homogeneity of the soil from which all samples were taken. Furthermore, from an experiment in which three samples were drawn from pipe No. 3 in quick succession, the results did not show any significant variation in values. Thus the drawing of one 3.88-liter sample does not affect the radon-content of this level. The bottom ends of the pipes were left open, while the top ends were closed with stop-cock arrangements. A fourth pipe of 200 cm was lowered subsequently on July 4, with the expectation that a depth might be found in which a state of equilibrium might be established.

The radon was collected directly in previously evacuated ionization-chambers. Three such chambers (brass cylinders 13.1 cm in diameter and 28.2 cm in height, with a volume of 3.88 liters) were used in each experiment, in connection with a Wulf bifilar-electrometer. With the additional fourth pipe a new chamber was added. A second electrometer loaned through the courtesy of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington was substituted in place of the first which had to be returned to the Bartol Research Foundation of the Franklin Institute. In an applied field of about 23 v/cm the fiber of the electrometer and the inner electrode of the chamber connected with it were charged negatively in order to obtain a well-defined value of the saturation-current by having the Ra-A atoms which are positively charged deposited at the inner electrode.

A standing from two and a half to three hours in the field is necessary in order to establish equilibrium between radon and its decay products (Ra A, B, and C). Experimentally it was found that the saturation-current measured one hour after filling the chamber was 86.6 per cent of the maximum value reached after three hours.

From a standard radium solution of 10^{-9} gram of radium procured from the National Bureau of Standards the calibration of the apparatus gave an average value of 1.68×10^{8} v/sec for one curie. This corresponds to 5.28×10^{6} electrostatic units of current per curie, taking the capacitance of the Wulf electrometer plus the ionization chamber as 9.4 cm, as calibrated with a Gerdien variable condenser.

Results obtained--In spring, summer, and fall the ground is entirely free from sub-freezing temperatures. From the curves obtained as plotted on the graph (Figures 1 - 3), with the experimental days as the abscissa and the radon-content in (curies/cc) $\times 10^{-14}$ as the ordinate, it is seen clearly that the radon-content increases with depth. During the latter part of May, all of June, and the first part of July, 1944, we observe at times sudden and large changes in values, but from July 15 to the time of the great hurricane of September 14, which swept the New York Area, we notice more constant values for all pipes. Subsequent to the hurricane and the accompanying heavy rains there is an increase in values continuing high with slight fluctuations till the heavy snow, sleet, and ice-covered ground season of January to February, 1945, when a great increase in the shallow layers is obtained, establishing almost the same values for all pipes. It may be mentioned that this effect is similar to the one obtained by BENDER in Austria in the winter of 1935 [2], which may be explained by the fact that the ground-conditions at both places under consideration were the same.

Previously, it was found and substantiated again during the winter of 1944-45 that frozen ground was the strongest factor in producing high values of the radon-content in the soil. The warmer season shows lower and more constant values under more stable ground-conditions.

Barometric-pressure influence--Up to the present investigation, it has been maintained that an increase in pressure caused an increase in the radon-content of soil-gas, while a decrease in pressure caused an opposite effect. This was based on the general fact that a greater pressure caused less radon to escape into the free atmosphere, whereas a diminishing pressure allowed a quantity of radon to escape from the ground.

SIMPSON [3] in Lapland (1905) in studying the radioactivity of the free atmosphere found an increase with a falling barometer, although the activity is not necessarily higher with a low barometer than with a high one. JOLY and SMYTHE [4] in Dublin (1912) from an examination of the barometric chart could not observe any influence of atmospheric pressure on the radon-content of soil-gas except where fluctuations are accompanied by storm, rain, etc. WRIGHT and SMITH [5] in Manila (1915) endorsed the statement of SIMPSON for the free atmosphere, but in their meager eight observations of the emanation-content of soil-gas they make no mention of pressure-effects.

BENDER [2] from observations in Innsbruck, Austria, in 1934-1935, asserted that a rise of barometer during the previous 12 hours before the intake of soil-gas favored the collection of emanation in the ground, whereas a drop in the barometric pressure caused a better exchange of ground-air with the atmospheric air and thus a lessening of the radon-content in the soil-gas. BENDER also observed that a higher absolute air-pressure causes greater emanation-content than lower absolute values of pressure. It must be kept in mind that in all these investigations and references the upper layers of the ground are under consideration.

To study accurately this pressure-phenomenon, it is necessary to take daily readings over a period, and to repeat this many times. Again, it is expedient to avoid wet seasons when the radon-content of the soil-gas is greatly under the influence of water in the soil. While BENDER made 116 measurements, still his study of the rise and fall of pressure is over periods with intervening days omitted. The author thinks that a more effective study (now being carried out) of the pressure-effect would be to make many measurements of the surface pipe over the course of the same day.

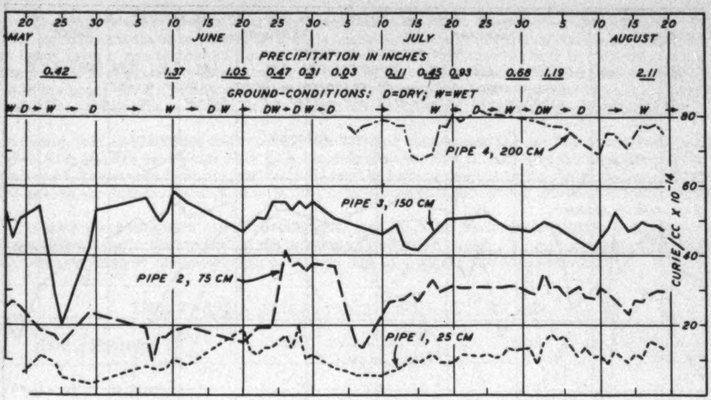

Fig. 1--Depth-curves of radon in soil-gas, May to August, 1944

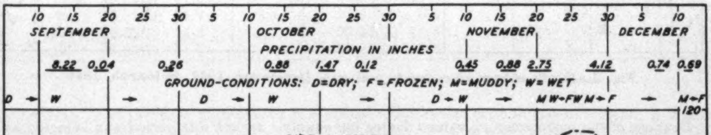

Fig. 2--Depth-curves of radon in soil-gas, September to December, 1944

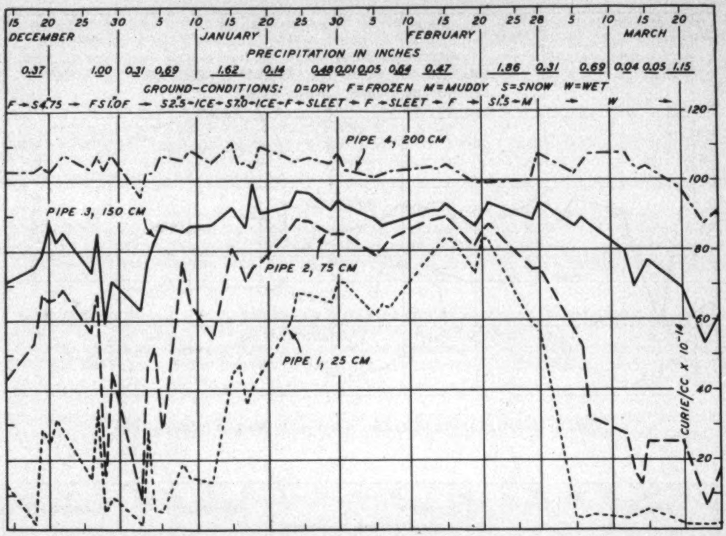

Fig. 3--Depth-curves of radon in soil-gas, December, 1944, to March, 1945

Because of the more constant values during the summer season this period was selected as the most suitable for the study of the pressure-influence, although consideration was given also to the winter period. Daily variations of pressure in consideration of the values of radon obtained at various depths, show that a rising barometer causes a decrease in the radon-content, and that a falling barometer increases the content of radon in the soil-gas. This observation is not in opposition to the general belief that the total amount of radon in the ground is increased by a rise in pressure and decreased by a drop in pressure.

Table 1 gives the number of comparative days which favored and those which opposed the interpretation that the direction of the pressure-change is in some inverse proportion to the change of the value of the radon-content.

Table 1--Comparison of days favoring and not favoring hypothesis that direction of pressure-change is in inverse proportion to radon-content

Season	Date	No. days favored (a) or opposed (b), pipe No.			
		1	2	3	4
(A) Summer	May 17 to Oct. 6, 1944 (237 readings used)	69(a) 20(b)	23(a) 27(b)	28(a) 14(b)	22(a) 14(b)
(B) Fall and Winter	Oct. 6, 1944 to Mar. 27, 1945 (169 readings used)	22(a) 16(b)	24(a) 17(b)	24(a) 19(b)	17(a) 30(b)

Many of the exceptions could be explained by reason of some other influence such as water-content, wind-velocity, sudden high solar radiation. Since we are studying Nature as it is there seems to be no known method of studying one influence isolated from all other influences over a period. The lack of uniformity may be due to variations in the strength of the content when under the influence of mixing. Again, the extent of increase of the radon-content with greater depths is not known at our point of observation while certainly the 200-cm depth of pipe No. 4 would come under the influence of the greater radon-content of still lower depths.

Apparently when atmospheric pressure decreases the upper layers are giving off some of the radon-content into the free atmosphere while these same layers are fed by the richer content of the lower layers, due to upward flow of air from the depth, and thus there is in evidence an increase in content gradually migrating upward. When the atmospheric pressure increases the soil-gas in the upper layers is mixed with additional atmospheric air which is poor in radon-content. This diluted admixture is in turn drawn deeper into the ground, causing a decrease in content.

Again, just as SIMPSON observed that for the free atmosphere the activity is not necessarily higher with a lower barometer than with a higher one, so here for soil-gas the gradient of pressure is of more importance than whether the pressure be high or low. It is the rising of the pressure that causes the decrease and the decreasing of pressure that causes the increase of radon-content.

Table 2 gives values of radon-content from pipe No. 1 for various barometric pressures; "D" means decreasing pressure during the previous 12 hours of intake, "I" means increasing pressure, "C" means constant and unchanging pressure, and "V" means variable pressure.

Table 2--Radon-content in (curies/cc) × 10^{-14} for pipe No. 1

Date	Pressure	Content	Date	Pressure	Content	Date	Pressure	Content
	in			in			in	
May 17	30.03(D)	10.5	June 23	29.95(C)	13.2	Aug. 4	30.15(I)	15.7
18	30.10(I)	5.8	24	29.60(D)	13.6	5	30.03(D)	16.4
19	30.30(V)	5.8	July 10	20.25(I)	5.6	14	30.10(D)	9.2
June 6	30.17(D)	8.1	11	30.25(C)	6.4	15	30.13(D)	11.8
7	30.05(I)	7.5	12	30.15(D)	6.9	16	30.02(D)	10.3
8	30.35(I)	7.0	31	30.20(I)	13.5	17	29.96(D)	14.7
20	29.81(D)	18.7	Aug. 1	30.34(I)	8.5	18	29.95(I)	14.3
21	29.85(I)	12.4	2	30.35(C)	14.8	19	30.25(I)	13.2
22	30.01(I)	11.2	3	30.10(D)	17.6			

On May 18 an increase in pressure has caused a noticeable drop in radon-content. A slight continued increase and then a change in direction on May 19 gave almost the same reading. On June 7 there was an increasing pressure with an absolute value lower than the previous days' decreasing value. The highest pressure on June 8 gave the lowest value. While pressure was constant on June 23 the content increased normally by radio-active decay, and continued to increase with drop in pressure on June 24. The constant pressure of two days, July 10 and 11, caused a greater accumulation of radon, and a slightly further increase with a drop in pressure on July 12. Again a constant pressure contributed to the accumulation of radon with a subsequent increase on August 3 aided by a decreasing pressure. The reading of August 16 was an exception. This may be explained by a high temperature of 33°C with a strong solar radiation decreasing the content.

BENDER asserted that higher pressures mean higher content while lower pressures point to lower content. In taking the averages of all the pipes for different pressures in the summer period of reasonable constancy of the curves, covering the experiment up to the time of the hurricane just prior to the great increases of radon-content, the results shown in Table 3 were found. Radon-content is in (curies/cc) × 10^{-14} and pressure is in inches of mercury. The numbers in parentheses indicate for pressures the number of days with the same pressure, while those following radon-content are the number of experimental readings involved in obtaining the average.

The average values for the various pressures show that where there is a reasonable number of experiments involved there is a decrease in content as the pressure increases in value. This effect is not so pronounced in the deeper pipes.

From the observations of the effect of the pressure gradient the following conclusions are drawn for the radon-content within 200 cm depth of the soil-gas: (1) A decreasing pressure causes an increase in radon-content; (2) a rising pressure causes a decrease in radon-content; (3) higher pressures tend to lessen the radon-content while lower pressures tend to increase the emanation.

Table 3--Pressure and radon-content in (curies/cc) × 10^{-14}, summary for summer

Pressure	Radon-content in pipe No.			
	1	2	3	4
in in				
29.60 to 29.69 (1)	13.6 (1)	18.9 (1)	55.9 (1)	.....
29.70 to 29.79 (0)	.....	.....	.....	.....
29.80 to 29.89 (5)	12.9 (5)	21.1 (5)	48.0 (3)	73.8 (2)
29.90 to 29.99 (7)	12.8 (7)	28.3 (7)	48.7 (4)	77.6 (5)
30.00 to 30.09 (11)	11.5 (11)	28.6 (8)	51.1 (9)	76.7 (5)
30.10 to 30.19 (14)	10.2 (14)	27.4 (12)	47.9 (11)	76.8 (8)
30.20 to 30.29 (14)	10.8 (14)	27.8 (13)	47.1 (11)	77.2 (7)
30.30 to 30.39 (10)	9.2 (10)	25.2 (9)	47.3 (6)	73.6 (7)
30.40 to 30.49 (2)	9.5 (2)	29.8 (2)	49.7 (2)	69.8 (1)

Wind-velocity--By BERNOULLI'S principle a wind at the surface of the ground would cause a lowering of pressure with a consequent emission of soil-gas into the free atmosphere. Since the wind comes in gusts usually it would be expected to have no great effect upon the lower layers. The wind causes a continual exchange of soil-gas into the free atmosphere. On the other hand, atmospheric air seeps into the ground when the wind subsides between two gusts. This would decrease the radon-content of the soil-gas at least near the surface.

If a high-velocity wind should cause a decrease in the radon-content, the number of periods of consecutive days of high wind which favored the above interpretation and those which opposed it are: (A) Summer, 10 favored and 3 opposed; fall and winter, 11 favored and 2 opposed. In deriving these, only wind-velocities of 25 mi per hr or more were considered. There never was during the summer period a high wind-velocity of long duration. Thus this effect upon the radon-content was felt only in pipe No. 1 and mostly without any great variation in values.

The fall and winter seasons presented longer periods of strong winds which manifested a greater effect upon the radon-content of the soil-gas. While certainly during this period the variable ground-conditions affect greatly the radon-content, still the majority of the troughs or lows on the graph occur during periods of strong winds. Even during the high-value period of frozen ice-covered ground, the various troughs occur at a time of strong winds, though not with the same intensity as when the ground is not covered.

Table 4 gives average wind-velocity for the hours mentioned previous to the intake, and the associated radon-content.

Table 4--Wind-velocity and radon-content in (curies/cc) 10^{-14}, pipe No. 1

Date	Wind-velocity and interval		Radon-content	Date	Wind-velocity and interval		Radon-content
1944	mi/hr	hr		1944	mi/hr	hr	
Sep. 21	12	24	21.9	Dec. 11	10	24	31.8
22	28	8	17.9	12	36	12	7.2
Oct. 30	32	24	17.3	13	33	24	5.3
31	15	24	27.8	14	27	24	12.3
Nov. 6	48	12	12.8	Dec. 26	38	12	14.6
7	33	24	28.1	27	11	12	34.3
				28	39	24	4.8
Nov. 21	36	10	42.8	29	27	24	8.9
22	34	24	23.2				
				Feb. 19	28	12	73.3
Nov. 29	7	27	38.2	20	9	24	83.1
30	38	7	7.7				
Dec. 1	43	24	2.8				

From the graphs it can be observed that four of the above periods showed a possible influence also upon the deeper pipes. In some of the readings above it is noticed that a drop in wind-velocity favors an increase in radon-content. It is to be noticed that for November 7 a continual, though less strong, wind gives rise to an increase in content, while on November 22 a slightly lower wind gave a decrease in content. In the former case there was a definite let-up in the wind, while in the latter case the reading for November 21 is rather high because of an unusual drop in pressure from 30.17 to 29.61 inches for the previous 24 hours. Still the continual wind did decrease the radon-content.

Ground-temperature--According to the BOYLE-CHARLES law the soil-gas expands approximately 1/273 of its volume for each degree increase in temperature. Such gas under the influence of rising temperature will increase in volume and thus dissipate the radon-content proportionately. A drop in temperature will cause contraction of the soil-gas and an increase in the strength of the radon-content.

The daily variations in temperature of the ground are not great. The greatest variation is noted in the uppermost layers. In the summer months the solar radiation is extremely strong during the course of the day. In August, 1944, there was a prolonged hot spell which should have clearly shown the influence of high temperatures. Yet these two months do not give the lowest values of the whole period of the experiment, but rather indicate a constancy of values for the 25-cm and 75-cm pipes. Again the increase after the time of the hurricane to winter values was not due to the great drop in temperature of the ground for the temperature during this period was the same as for the month of May when we have very low values. Variations in ground-temperatures are never great and occur slowly, and play at most a very small part in affecting the radon-content.

In examples of Table 5 there is apparent an influence of temperature-change at a time when the pressure remained constant and the wind velocity was decreasing.

Table 5--Influence of temperature-change with constant pressure on radon-content in (curies/cc) × 10^{-14}, pipe No. 1

Date	Ground-temp.	Pressure	Wind-velocity	Radon-content
1944	°C	in	mi/hr	
July 5	22.5	30.30	14.5	6.3
July 6	25.2	30.30	12.2	5.7
July 25	27.0	30.06	13.3	11.6
July 26	29.2	30.07	9.8	10.2

The hurricane of September 14--The hurricane produced a great increase in the radon-content of all the layers, to values which fluctuated variably but continued high, as shown in Table 6. This effect must have been produced as a result of great change in the ground-conditions. The heavy rain of 8.2 inches definitely clogged up the capillaries of the upper layers, captivating the content in the deeper layers, such that these values constantly continued to increase. Certainly, much of the rain flowed off since the Earth could not absorb the quantity of rain that fell in a few hours. Still subsequent observations showed that a great amount was absorbed since the water-content was present in the ground for weeks later. It is this sealing effect that has produced the high plateaus.

During the above period only 0.3 inch of rain fell after the hurricane, thus not of great influence towards the high values. The peak-value of 106.1 × 10^{-14} curies/cc of October 4 at 200-cm depth is the maximum value ever reached in either this or the previous winter experiment, though it must be remembered that in the former work the deepest depth investigated was 150 cm. The highest value of the pipe No. 3 of 80.4 on September 28 occurred when there was no apparent reason for such a rise, for even the other pipes were somewhat constant at this time. The peak value of pipe No. 2 of 57.9 on September 16 was due definitely to the clogging effect of the upper layers. Pipe No. 1 reached its highest value of 29.1 just before the hurricane due to the clogging caused by the previous rain of 2.8 inches on September 13, and subsequently dropped in value due to occlusion.

Conclusions--(1) Dry ground, obtaining during the summer season, produces stable conditions such that constant values are established at each layer, and that the increase of radon-content with depth is definitely observed.

(2) Frozen, snow-and-ice covered ground produces the greatest values in all pipes, and if this condition persists for a reasonable period it causes all pipes to approach the same value.

Table 6--Radon-content in (curies/cc) × 10^{-14} during hurricane of September, 1944

Date	Radon-content, pipe No.			
	1	2	3	4
Sep. 12	17.7	31.4	41.1	71.4
13	21.7	31.1	44.1	68.9
14	29.1	44.1	. . .	71.5
15	18.0	49.3	61.1	84.5
16	17.2	57.9	69.1	. . .
18	21.7	50.8	. . .	92.7
19	28.9	48.4	57.3	92.4
20	20.2	48.2	. . .	97.9
21	21.9	48.9	. . .	97.3
22	17.9	48.8	69.2	99.1
26	17.5	50.0	71.8	100.7
28	17.6	51.8	80.4	101.0
Oct. 2	27.3	55.7	72.5	101.9
4	16.4	53.3	72.8	106.1
5	21.2	52.3	72.5	105.0
6	19.4	51.1	69.8	103.2

(3) Barometric pressure causes, at least to a depth of 200 cm, a variation such that an increasing pressure tends to decrease the radon-content, while a decreasing pressure produces an increase in radon-content.

(4) High wind velocity when present for a number of hours will reduce the radon-content in the top layers of the ground.

(5) Ground temperature changes have no noticeable effect upon the radon-content.

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NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 224, 265, 274, 297, 300, and 304)

NOTES

American Congress of Surveying and Mapping--The Fifth Annual Meeting of the American Congress of Surveying and Mapping was held at the National Archives Building, Washington, D. C., on June 23, 1945, President George D. Whitmore presiding. Following the business meeting, which included the annual reports of the officers, there was a panel discussion on "Cooperation among the technical societies" in which the American Society of Photogrammetry was represented by O. M. Miller of the American Geographical Society; the Washington Section of the American Society of Civil Engineers by R. M. Wilson of the United States Geological Survey; the American Geophysical Union by C. H. Swick of the United States Coast and Geodetic Survey; the Society for the Promotion of Engineering Education by Frank C. Mirgain of Rutgers University (paper read by George D. Whitmore in Professor Mirgain's absence); and the American Congress on Surveying and Mapping by Frank S. Borden of the United States Coast and Geodetic Survey.

Officers for the ensuing year are Frank S. Borden, President, Richard T. Evans, Treasurer and Acting Executive Secretary, and A. L. Shalowitz, Editor. The ten regional vice-presidents remain unchanged. Surveying and Mapping, the quarterly journal of the Congress, has recently been considerably enlarged and improved and has greatly helped to promote a steady growth of the Congress during the difficult war years, which constitute its total life. It was organized in 1941.

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THE GENETIC SIGNIFICANCE OF PARÍCUTIN [a]

L. C. Graton

When Parícutin, born February 20, 1943, shall have completed its destined activity, the chances seem to be that it will not deserve listing among the great or otherwise outstanding volcanoes of the world. As one among the many that have been observed in eruption, it reveals little that is unique or extreme. On the contrary, it is displaying a range of behaviors that are moderate and conventional.

It might therefore be inferred that Parícutin can have only a restricted and casual scientific appeal. Just the opposite is true. If Parícutin were a freak volcano, what could be learned from its study would have narrower application and hence lesser value. Its chief claim on the attention of scientists arises from its normal and typical character and behavior--about which our knowledge is still all too scanty.

That Parícutin stands as a fair sample of volcanic action of the "central" type finds confirmation of two kinds, the one general, the other local. On the one hand, it belongs in the overwhelmingly dominant category of the world's volcanoes, those which yield chiefly fragmental products [see 1 of "References" at end of paper]. On the other hand, even more emphatic evidence of its typical character is found in the geologic and physiographic province within which it lies.

This extensive province, the Mexican Mesa Central [b], reveals two conspicuous features, related yet contrasting. Upon the major nodal framework represented by the older, magnificent volcanoes is superimposed a smaller-textured pattern of countless volcanic cones of more recent origin and modest size. [c] It is to the younger group that particular importance here attaches.

Occurring by the thousands over a belt some 500 by 100 km in area and stretching through the States of Mexico, Michoacán, and Jalisco, these younger, smaller volcanoes, especially when viewed from the air, suggest that a great patch of the Earth's face is crowded with the pustules of smallpox. In size, shape, and structure these protuberances appear almost as if from a single mold, a similarity all the more evident because their original details have suffered so little erosional modification. The conclusion that they must be very young is, of course, fortified by the fact that a typical member of this series, Jorullo[d], about 75 km to the southeast of Parícutin, originated, grew, and died less than two centuries ago. The genetic unity of all these younger volcanoes is further indicated by their invariably basaltic product, whereas the earlier and grander volcanic series comprises rock varieties chiefly or in part of intermediate character. Nowhere are these small basaltic units more numerous than in the western half of Michoacán, nor than in the immediate environs of Parícutin where there are hundreds within an area of 450 sq.km.

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[a] This paper is a revised and somewhat condensed version of part of an article "Ciertos aspectos genéticos del Parícutin, nuevo volcán de Michoacán [Instituto de Geologia, Estudios volcanólogicos: El Parícutin, pp. 59-91, 1945].

[b] This is the designation applied by ORDOÑEZ [2]; ROBLES RAMOS [2] calls the province the Cordillera Neo-Volcanica.

[c] Collectively these two groups of volcanic structures, together with their flanking flows, their occasional satellites and their great aprons of ash, almost exclusively dominate the geomorphology of this region. Not only is this true in the distribution and contour of the eminences, but equally also in the accidental shape and placing of the intervening depressions which, bearing only slight and incidental relation to the conventional pattern that results from degradational processes, occur mainly as hollows, large and small, many of which have no surficial outlet, and thus constitute either land-bound lakes (and former lakes of which the lacustrine sediments, composed chiefly of volcanic material, are now revealed) or empty bolsons, as local ground-water level may determine. The landscape of this extensive region, so overwhelmingly constructional yet so highly diversified and accentuated, is impressive, indeed. Probably nowhere else in the world is there such great concentration of conspicuous volcanic cones over so large an area.

[d] A photograph of the main cone of Jorullo, published by ORDOÑEZ [3], reveals greater erosional modifications than is shown by most of the cones farther north, although these latter antedate historical record. This apparent anomaly in evidence of age is probably to be explained by the fact that Jorullo lies just to the south of the high plateau, at an elevation something like 1000 meters lower and within the belt of frankly tropical temperature and precipitation, thus suffering more vigorous decomposition and erosion.

So far as can now be judged, Parícutin is in process of becoming a typical member of this extremely numerous group of smaller volcanoes. This means that results from the series of investigations now going on will presumably apply not alone to Parícutin but also to the thousands like it.

In considerable degree this is a unique situation. For the most intensive volcanological studies carried out heretofore have dealt with volcanic units of quite distinctive and contrasting characters, notably Vesuvius and Kilauea; with the result that the knowledge gained from even these best organized and most continuous investigations, when brought together for summary, is in considerable measure non-corroborative and in spots actually contradictory. All the more welcome is it to encounter a volcano which is in process of repeating, as if for our benefit, an eruptive program which has earlier occurred at almost innumerable other points in the same region, as well as in various other regions.

Beyond the fact that Parícutin serves as the current working model of a great group of dead volcanoes is the still more gripping fact that it is a new volcano. For in certain respects a new volcano is a more appropriate and reliable object of study than an old one. By its very youth it is relatively simple. This is a great advantage, since even the simplest volcano presents many more problems than we yet know how to handle. An old volcano confronts us with the superimposition and entanglement of many past complexities. The problem of determining what happened and what is happening is thereby rendered inherently more difficult. Moreover, this bewildering complexity adversely influences our mental processes. Because the old volcano has concealed much of its earlier products and processes by the mantle of its subsequent effusions, there is all too often temptation to take advantage of the concealment by invoking and insisting on this, that, or the other ad hoc condition in the concealed portion in order to reach an explanation of the part revealed. Thus we find postulation of subsidences or uplifts of the surface, or off-drainings of lava, or similarly hypothecated structures or processes whose chief strength often seems to lie in the fact that no one is able to disprove them.

A new volcano, on the other hand, bursts out to the surface at a spot which, whatever its prior history, surely constitutes a simpler and better-understood foundation than what is about to be erected upon it. The new volcano thus does not incite the mental temptations that so often warp understanding of older volcanic edifices. Speculation about what we cannot see is inescapable; but obviously we draw safer conclusions in proportion as observation can supplant speculation. ARISTOTLE may well have had something like this in mind when he wrote: "He who sees things grow from the beginning will have the best view of them."

Parícutin, moreover, is a new phenomenon at a spot already familiar. By happy fortuity, an aerial survey of this region in 1934-35 preserved with photographic precision details of the group of earlier cones and rugged flows that encircle the ash-plain whence arose the new volcano. Surely no such detailed and reliable record exists regarding the precise site of birth of any other volcano.

Near-by telephone service and easy access by automobile facilitated prompt beginning of scientific study. Seen at the instant of its birth, the new volcano's rate and manner of growth were, within 18 hours, being objectively registered by color cinematography. In less than three days, EZEQUIEL ORDOÑEZ, veteran student of Mexico's volcanoes, began the campaign of observation and interpretation in which have now joined many other scientists of varied specialized interests pertaining to the new phenomenon. For professional and amateur photographers the spectacle of the volcano has been a steady magnet, to swell the reliable pictorial record from different viewpoints and of different phases of the activity on a variety of dates. Even despite the various limitations imposed by war conditions, it is manifest that by the end of its period of activity there will have been observed, digested, and put on record by experienced investigators a far fuller account of fact and relationship about Parícutin than exists regarding the birth and development of any other volcano.

Finally, Parícutin promises to contribute to an understanding of Mexican volcanology by focusing renewed attention on the entire volcanic picture of Central Mexico.

The larger Mexican volcanoes are usually classed as of Tertiary age, while the smaller ones are not earlier than Quaternary and many are Recent. The two size-groups also show certain petrologic differences and diverse patterns of distribution, as already mentioned. It would therefore be easy to put them into two contrasting classes, and thence, following good authority, to conclude that the respective classes have different derivation and significance. Let this be briefly examined.

In summarizing the conclusions of others in the light of his own experience and deductions, DALY [4] recognizes two kinds of central volcanoes, principal and subordinate, which he distinguishes not only by size but also by other and more fundamental criteria. Those of the principal class he finds to be characterized by long and strong activity, large outflow of lava, and alignment in chains; whereas those of the subordinate class show brief activity, small yield of lava, and arrangement in clusters instead of in linear or arcuate systems, with perhaps also some non-linear crustal deformation.

These differences DALY believes to be consequences of contrasting modes of origin. The principal volcanoes are visualized as fed directly from abyssal bodies of magma through deep-reaching master fractures. The subordinate volcanoes, on the other hand, are thought to represent the erratically distributed blowholes or relief-vents of laccolithic or less regular magma bodies, satellitic with respect to the great abyssal units and injected at such shallow depth as often to occasion visible doming of the overlying surface.

These are profound distinctions. DALY recognizes the possibility that certain instances may give difficulty in applying the distinguishing characteristics. But the outward differences between the larger and smaller Mexican volcanoes suggest such degree of coincidence with the respective sets of criteria just mentioned as to raise definitely the question whether they really have such unlike sources and depths of origin as postulated.

Opportunity is thus offered for extending the present wave of interest in Mexican volcanology to a wider range of thought and inquiry than that applying to the single unit, Parícutin. And, in further attack upon the problem of the principal versus the subordinate volcanoes, there should be great advantage in the intimate association in the same area of numerous large and countless small volcanoes, both groups so young and unimpaired that representatives of each group have been observed in eruption within historic time.

This situation contrasts strikingly with the factual basis upon which the classification into principal and subordinate and the thesis of their different origins were established--a basis pieced together from examples widely separated, in diverse structural settings, and differing in age and state from presently active volcanoes to ancient units of which only deeply eroded necks survive. Such handicaps have made analysis and conclusion more difficult, and also have permitted special pleading in favor of given views that might not have survived had critical checks been possible.

With the thought of stimulating interest in an investigation of this important problem by those intimately familiar with Mexican geology, certain comments may be advanced indicative of doubt whether the profound genetic difference proposed between principal and subordinate volcanoes is truly applicable to this Mexican province.

In considering the criterion of spatial arrangement[e] attention may first be given to the rock structure. Exposures of the pre-volcanic rocks within the volcano-rich area appear to be too scant and sparse to disclose a systematic arrangement of structural weakness into and accordant with which the volcanic vents would naturally have penetrated.

The volcanic rocks themselves, with their characteristic constructional topography, appear to have been relatively immune from subsequent structural disturbances, except for the many successive puncturings by new volcanoes. It is true that there are some elongated ridges; that faults and other fractures can be found and some of these carry ores. But it seems a long step from the scattered distribution and the varied azimuths of these fractures to the establishment of a consistent structural pattern for the province or for any considerable fraction of it. Dominant structural trends, generally so easily detected from the air, are not in evidence when one flies over the region; this impression seems to be supported for the province as a whole by the topographic relief shown on the aviation charts for this part of Mexico, and for the vicinity of Parícutin by the aerial photography already mentioned.

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[e] The personal impressions here recorded do not coincide in all respects with conclusions reached by the Mexican geologists as to the clarity and certainty of the structural pattern of this volcano-rich region. From the advantage of their far greater knowledge of the area, it is hoped that with generous patience they will regard this expression of doubt by a newcomer in the manner intended--a method of pleading for further evidence on this appealing and important problem.

As for the arrangement of the volcanoes themselves: the striking east-west lineation of the more conspicuous volcanic peaks[f] of Mexico has long been emphasized.[g] But the perfection of alignment, in terms of spacing of the several volcanoes, is by no means equal to that of such striking arcs as the Lesser Antilles or the Aleutians, and therefore leaves some doubt whether the lineation signifies a single controlling fracture-zone or a more accidental distribution within some broad locus. When consideration extends to Mexican cones in the intermediate rank of size, which, nevertheless, are large enough and old enough to merit presumptive inclusion with the "principal" volcanoes, linearity is still less evident.

Among the countless smaller younger cones of the "subordinate" group, there is likewise no hint of orderly arrangement. One may only say that they occupy a rather irregularly bounded belt more or less centered on the narrower strip that contains the larger volcanoes. In instances where two or more of the smaller volcanoes lie close together along a line, suggestive of control by a common fracture, such as the major and three minor cones at Jorullo and the Parícutin-Zapicho pair, the directions of such lineations reveal no regional trend or unity; each is apparently determined independently by the conditions existing in its immediate locality. It is common observation all over the world that satellitic or parasitic cones on the flanks of a mother volcano tend to be arranged along radii emanating from the latter. This implies the frequency with which the forces of volcanic explosion along a major vent cause radial rupture[h] in the adjacent rocks of the shallower depths and thus produce subordinate avenues of egress for fractions of the magma that had previously been using the main conduit. The numerous small-scale examples of alignment among the Mexican cones may well be ascribable to such local syngenetic fracturing, rather than to systematic, regional directions of pre-existing weakness.

The presence in a single region of potential representatives of both the "principal" and the "subordinate" volcanoes offers opportunity for test of their positional controls not previously made. If the "principal" volcanoes of Mexico be limited to those majestic ones which possess a fair degree of geographic alignment, the fracture or set of fractures which is assumed to have localized them presumably existed when their sites were chosen. When, later, the weaker volcanoes of the "subordinate" group came into existence, it would seem that these should have eagerly taken advantage of intervening unoccupied positions on the master fracture or fractures if such had really existed. This should give a striking row of small volcanoes crowded along the line between the grand ones; but there seems to be no such marked localization of the smaller cones nor of known dikes of basaltic composition. To explain this by the assumption that the weakness which localized the earlier volcanoes had become healed by the time the smaller ones appeared would seem to forget the evidence inherent in the fact that Orizaba, Popocatepêtl, and Colima have erupted within historic times and steadily display fumarolic phenomena.

Admittedly some condition caused both the large and the small volcanoes to develop in a single belt of east-west elongation. This condition may have been east-west fracturing on an appropriate scale. But whatever the cause, there seems little in the known facts of distribution and structural control to support the specific idea that the two groups of volcanoes had different depths and conditions of origin.

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[f] Orizaba, Malinche, Ixtaccihuatl, Popocatepêtl, Ajusco, Toluca, Tancítaro, and Colima--Descriptions of the geology of these volcanoes are to be found in the writings of J. G. AGUILERA, E. ORDOÑEZ, T. FLORES, and P. WAITZ.

[g] The tendency among professional volcanologists to exaggerate the extent to which volcanoes occur in lines or arcs is not to be overlooked. For the Mexican volcanoes there has continued since the days of VON HUMBOLDT a round of controversy as to just where "the lines" should be drawn. The naïve discussion of SAPPER [5] reveals how subjectively such conclusions are reached and what great uncertainties enter into the result finally adopted. Pen, ruler, and map in the library are sometimes supplemented by a view from the summit of one or more of the high peaks. After some fitting and trying, in order to decide whether to put "the line" through this volcano or through that one, a compromise position is finally adopted--and, without other evidence, is confidently announced as a controlling master fracture! When a single line cannot, without excessive distortion, pass through all the volcanoes, some are left dangling and neglected, or else the device is adopted of showing two or more "parallel fractures." To the mining geologist, all this seems a strange manner of synthesizing geological structure.

[h] Radial fractures that differ from these only in scale are commonly produced by an explosion of dynamite in a drill-hole in brittle rocks.

A similar conclusion comes from consideration as to age. For although the grand volcanoes are notably older than the smaller ones as judged by time of beginning, they are contemporaneous in the sense that both groups have been active in recent times. Therefore, the common separation into Tertiary on the one hand and Quaternary or Recent on the other is not so significant as it sounds.

The great volcanoes have yielded lavas of wider variety in composition than those characteristic of the "subordinate" group. But it is not clear that this variety in the great volcanoes suggests difference in fundamental nature and depth of source (intermediate compositions would not be expected from a deeper source than basaltic compositions) rather than a consequence of magmatic differentiation permitted during their greater duration of active life. It is to be hoped that the stimulation of interest occasioned by the birth of Parícutin may lead to detailed restudy of the Mexican lavas, from the grand and from the small volcanoes, both in field and in laboratory, with these questions especially in mind.

It is to be recalled and recognized that the linking of the "subordinate" volcanoes with laccoliths or other shallow-seated intrusive bodies draws support chiefly from the direction of interpretation and deduction, and rests on extremely scanty objective evidence. Nothing in the Mexican picture points with any clarity toward such an explanation for the countless smaller volcanoes. On the contrary, the great size of the area over which they so plentifully occur, the absence of the doming which a laccolith or similar shallow injected body of such dimensions should be expected to cause, and the composition of the lava itself, rare in laccoliths, combine to give what would seem to be rather imposing probabilities against such origin.

Perhaps the most direct piece of evidence on the question comes from seismology. LEET and COLLINS of the Harvard Seismological Station have examined the seismograph-records from a considerable number of important stations of the world-shaking earthquake that immediately followed the birth of Parícutin. Professor LEET kindly informs me that the epicenter of this quake lay not far to the southeast of the point where the volcano broke through to the surface, and that by a new technique the depth of focus or hypocenter is interpreted to lie at a depth of some 40 km. This would qualify as a deep rather than a shallow source. Some, indeed, may be inclined from this to conclude that Parícutin is destined to become another of the great volcanoes instead of a member of the subordinate group. But the abundant testimony of Parícutin's hundreds of small, dead neighbors seems a safer basis of prediction. In any case, sounder conclusions will be possible when there shall be more examples of earthquakes related in time and epicenter to volcanic eruptions, and when the relatively new seismologic technique of determining depth of focus shall have had fuller trial.

The entire fate of the hypothesis that "principal" and "subordinate" volcanoes are basically different kinds of phenomena may not depend on the test of its soundness as applied to this province of central Mexico. But a test in this promising area should surely be made, so that further light may be gained as to the true significance of Parícutin.

As against all the foregoing factors that make Parícutin a highly important object of investigation, a few words need to be said on the debit side of the account.

The probability that Parícutin will never be a great volcano has earlier been hazarded. This, if true, will be related with a modest intensity and relatively simple variety of behavior.

It is conceivable that a volcano could become great in size merely by sufficiently numerous eruptions of mild intensity. But in general it seems to be true--in so far as either the historical or the geological record of activity permits judgment--that the great volcanoes have achieved their stature not only through long persistence of activity but also through a relatively intense variety of behavior. Indeed, these great volcanoes may have maintained activity over long periods primarily because they were from the beginning and long remained the sites of generation of unusually powerful subterranean forces. Longevity of a volcano implies the possession of sufficient energy to blow out every plug of lava that may congeal during an interval of reduced activity, to overcome every stoppage, during a long span of time; whereas in a volcano of lower vigor, some early impediment to easy emission, perhaps even the very first one, may throttle the entire unit for all time, or possibly force transfer of activity to some other outlet then more accommodating and not too far away. Most great volcanoes are broad and high; and plainly more energy is required to eject the materials to the top and the extensive flanks of a volcanic edifice that has attained hugh dimensions than in the case of a cone of modest size.

With the increase of scale and intensity--higher temperatures, greater pressures, larger throats, etc.--is likely to go a wider range and variety of behavior. A small volcano might blow away, or by outgushing lava drag away, a notable fraction of its light-weight, weak and essentially uncompacted cinder-cone. Parícutin has already done the latter on a modest scale several times, and some of its analogs in the region have performed likewise. But any such phenomenon is on so inferior a scale of intensity as to be a quite different kind of event from what happens in the catastrophic explosions of almost unimaginable intensity which rend, breach, or even almost destroy enormous cones, long compacted, hydrothermally cemented, and interlayered with massive lava, as at Temboro, Krakatao, Bandai-san, or Katmai. A small volcano like Parícutin does not and probably never will possess anything like the surging "lake of fire" at Halemaumau, the core of Kilauea; nor do any of Parícutin's neighboring relatives indicate that they possessed any such feature.

Parícutin, therefore, must probably be content with a reasonably modest range of intensity as well as of size, and thus will the variety of her phenomena probably remain relatively restrained and simple, and her expectation of life relatively short. But this might have the offsetting advantage of bringing the birth, activity, and death of Parícutin within so short a span that practically all the major events of its entire life-cycle could be observed and described by the same group of investigators.

Finally, it is possible that Parícutin may be charged with another short-coming. Someone, long ago, made the observation that although a number of new volcanoes had been known to break out, none of these is located outside a region previously characterized by volcanic action. Of course, each volcanic region had to have a first volcano; so it is possible that man may sometime witness one of these inaugurating events in a previously virgin area. But the statistical chances against it are very heavy. That the next new volcano will occur in this same province of central Mexico or in some other region similarly characterized by many and geologically recent manifestations of volcanism seems overwhelmingly more probable than that a site will be selected where, so far as known, no such previous activity had been evinced unless in time long past. And, of course, the same probability that applies to the "next" volcano applies with equal force to the second next, the tenth next, and so on. Therefore, the venerable generalization cited earlier in this paragraph, while true, is scarcely profound. Nevertheless, since then many of the treatises, whether long or short, that have dealt with the subject of volcanoes have deemed it necessary to include this all but self-evident assertion. We may expect, therefore, that Parícutin will soon receive condescending reference because it is new only in time and not new in place also.

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GEOLOGIC SETTING OF PARÍCUTIN VOLCANO

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A wide belt of young volcanoes, more than 500 miles long, crosses Mexico approximately along the 19th parallel, separating a region of comparative stability to the north from one to the south marked by instability, strong seismicity, and negative anomalies of gravity. To this volcanic belt belong such giant cones as Orizaba, Popocatepetl, Nevado de Toluca, and Colima, as well as the recently active cone of Jorullo and the new volcano, Parícutin. During Early and Middle Tertiary times, volcanism in Mexico was much more wide-spread, not only along the belt just mentioned but also to the north; during and since the Pliocene period, activity has been confined increasingly to this east-west zone.

As part of the cooperative study of Parícutin, now being undertaken under the auspices of the National Research Council and of a parallel Committee of Mexican scientists, a reconnaissance was made of an area of about 600 square miles around the new volcano, extending approximately between the towns of Uruapan, Paracho, Los Reyes, and Tancitaro. The work was financed by the Interdepartmental Committee for Cultural and Scientific Cooperation of the Department of State.

Within this area, the oldest rocks are deeply altered gabbros, poorly exposed in a hillock one and one-half miles southeast of Uruapan. These appear to be part of the same plutonic basement from which came the exotic blocks of quartz monzonite periodically ejected by Parícutin.

On this irregular plutonic floor there was deposited during Tertiary time a thick pile of lavas and pyroclastic deposits, dominantly of andesitic composition. These Tertiary rocks, provisionally called the Zumpimito formation, underlie the plain of Uruapan; they form the hills that enclose the plain on the south and east, and the deeply dissected mountains extending thence toward Apatzingán. They resemble and are probably of the same age as the volcanic rocks exposed in the rugged country between Morelia and Zitácuaro. East of Uruapan, this Zumpimito formation consists mainly of andesitic breccias, tuffs, and tuffaceous clays with subordinate lenses of rhyolite tuff and occasional flows of hornblende andesite and olivine basalt. South of Uruapan, it is formed principally of coarse, ill-assorted and unstratified breccias, apparently the deposits of powerful volcanic "mudflows." Westward, the content of fragmental debris diminishes as flows of massive andesite increase in number and thickness.

Within the area studied, the Zumpimito formation lies horizontally or almost so. No original volcanic forms remain; the mature topography is entirely erosional.

Six miles south of Parícutin, the formation rises to an elevation several hundreds of feet higher than the original base of the new volcano, and probably it also underlies the new cone at shallow depth. Nevertheless, among the ejecta of Parícutin, fragments of these Tertiary volcanic rocks are either absent altogether or only doubtfully present in very small number.

Following deposition and dissection of the Zumpimito formation, copious outpourings of andesitic lava issued from vents about five miles southwest of Parícutin. These built the huge, shield-shaped mass of Tancítaro Mountain, the summit of which, at an elevation of approximately 13,000 feet, towers a mile above the surrounding country. Even the visible diameter of this great cone exceeds seven miles and its buried extent may be twice as much. The volcano grew entirely by quiet effusions; interbeds of fragmental debris are conspicuously lacking. No trace of a crater remains, and the sharp-crested ridges that radiate from the summit plateau are separated by profound V-shaped canyons. To judge from this, the age of Tancítaro Mountain is probably late Pliocene and/or Pleistocene. Certainly the volcano was already extinct before the encircling cones of basalt began to develop.

The final phase of volcanism, beginning in the Pleistocene and continuing today, is marked by voluminous discharge of olivine basalt. Thousands of square miles of central and western Michoacán are covered by lavas indistinguishable from those now being poured out by Parícutin. Scores of large basaltic lava-shields and literally thousands of smaller cinder-cones diversify the landscape. Even the oldest of these volcanoes, though scored by deep canyons, retain much of their original forms, and none has been eroded sufficiently to reveal its feeding conduit. Close to Parícutin are clusters of youthful cones of similar origin and composition. What is happening today is merely a repetition of eruptions that have been going on intermittently in Michoacán since the Pliocene. In all this vast basaltic province, only two non-basaltic volcanoes have so far been recognized--one, near Cherán, consists of hypersthene andesite, and the other, close to the town of Tancítaro, consists of hornblende andesite. Petrographic uniformity is thus the outstanding feature of the province, as it is of the products now being discharged by the new volcano.

Taken as a whole, the basaltic volcanoes of Michoacán lie within the east-west volcanic belt that cuts athwart Mexico. Within this belt, however, most of the volcanoes appear to be distributed at random. Certainly all but a few of the larger volcanoes are scattered haphazard, and even the smaller cinder-cones are rarely alined for long distances along a common fracture. Cinder-cones cap most of the larger lava-cones, but they are most numerous in the depressions between those larger forms. A few are disposed radially on the flanks of the major cones and may rightly be considered as parasites on them, but typically the minor cones are dotted without order around the feet of the larger structures.

The cluster of minor basaltic cones around the lower flanks of Tancítaro Mountain is particularly dense. Precisely where the cluster is thickest, at the northeast base of the mountain, rises the new volcano, Parícutin. It should not be thought that this ring of basaltic cones around Tancítaro indicates them to be parasites of the older, andesitic volcano. On the contrary, the oldest of them did not begin to erupt until Tancítaro was deeply eroded. Once they began to develop, they hastened the denudation of Tancítaro, for each eruption blanketed the mountain with ash and so supplied the streams with additional power to cut. Today, at Parícutin, the role of volcanic eruptions in accelerating erosion is most vividly displayed.

Too little is known of the geology of Michoacán, particularly of the pre-volcanic history, to warrant extended discussion of the structural setting of Parícutin. Reference has already been made to the general lack of alinement of the younger volcanoes; note should be made, however, of a few exceptions. Near Paracho, several cinder-cones trend northeast to southwest along a line directed toward Parícutin. And at Parícutin itself, the principal vents and the main tremor-zone are oriented in the same direction. Elsewhere in the region studied, there are a few groups in which three or four closely-spaced cinder-cones are alined, approximately east-west or northwest-southeast. It must be emphasized again that such alinements are exceptional and that the lines are short.

An older, rectangular system of faults has long been recognized in Michoacán. The dominant fractures trend almost east and west. Among these are the ones that define the grabens of Lakes Chapala and Cuitzeo and the depression of Zamora. Subsidiary fractures trend approximately north-south. Vertical displacements along these faults are large and many of the fault-blocks are strongly tilted. Almost all of these faults antedate the growth of the younger basaltic volcanoes of Michoacán. Indeed nowhere within the area adjacent to Parícutin, nor in the region extending thence eastward through Lake Pátzcuaro to Morelia has a single fault-scarp been observed. The presumption is that the recent volcanism has not been accompanied by strong differential uplifts and that where the recent volcanoes do show a short alinement the controlling fractures are either tear faults or simply tension fissures. The general disorder of the younger volcanoes bespeaks an absence of large, throughgoing fractures; it suggests rather a series of discontinuous gashes such as might be produced by horizontal movements of small extent. Until more detailed analysis is made of the regional structures within the Neo-Volcanic zone of Mexico, it is idle to speculate further.

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OBSERVATIONS ON THE PRESERVATION OF PLANTS IN THE PARÍCUTIN AREA

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Abstract--The study of plant "fossils in the making" in the ash deposits at Parícutin is an unusual opportunity for comparison with fossil plants in the Tertiary ash deposits of western North America.

The Parícutin ash has destroyed much of the nearby forest, which is an upland temperate assemblage dominated by pines, oaks, crab-apple, and madrone. Buried plant-remains, including needles, cones, leaves, seeds, and twigs, as well as standing trees and shrubs, were studied in pits dug at sites selected to illustrate various conditions of plant growth and of different types of ash deposition.

Preliminary results indicate that (1) true fossilization, implying induration of the ash and mineralization of wood, has hardly begun; (2) processes of fossilization were highly selective so that the plants were not equally susceptible to preservation; (3) plant-remains were well preserved only if buried close to their parent trees or shrubs; (4) subaerial ash deposits contained more abundant and better preserved plant-remains than stream or lake deposits; (5) plant-remains in the subaerial deposits are the most likely to be destroyed by future erosion; (6) the best ultimate plant preservation will be in valley ash deposits buried by lava.

Reasons for study

The emphasis in modern paleobotanical studies is on inductive and analytical methods rather than on the purely descriptive. The interest is not merely in what particular species of fossil plants are discovered but rather in the total living forest which the fossils represent and the relations of that forest to its environmental setting. Insofar as possible, the ancient landscape and climate are reconstructed by means of the fossilized remnants of its original forest.

In the Tertiary deposits of western North America many such reconstructions have been made in areas of volcanic ash deposits. In these areas the ancient landscape and its forests have either disappeared or undergone such changes that their reconstruction must be based on inferences and analyses based on fossil remains. In the ash deposits adjacent to Parícutin Volcano, there is an admirable opportunity to make a careful check between the conclusions based on buried plant-remains and the actual forest still present in its physical setting. Of further interest at Parícutin is the study of conditions of fossilization and the state of fossilization reached by the buried plant-remains.

Methods of study

During six weeks in the Parícutin region, plant-remains were studied in the following situations: (1) on the surface of the ash both within and adjacent to the forest; (2) in vertical exposures of ash along stream courses; (3) in pits dug into the ash at sites selected to illustrate various conditions of sedimentation, including subaerial, alluvial plain, stream-channel, and lake-bottom deposition.

In each situation the buried or partially buried plant-remains were recovered for study by sifting of ash layers through a coarse screen. Observations were then made on the physical state of the recovered plant-remains and on the degree of correlation between the conditions inferred from the buried plants and the actual conditions in the adjacent forest.

Description of the present forest

The forest adjacent to Parícutin is an upland, temperate pine-oak association. There are two species of pines, two of oaks, a crab-apple, a madrone, and an alder on the hills and steeper slopes. The lower stream-channels are bordered by the same species of pines, oaks, and crab-apple, with the addition of one species of cherry, a lancewood, and a linden. Minor elements in the vegetation include ragweed, mimosa, and smilax. The gentle slopes between the hills and stream-channels were almost entirely under cultivation before the eruption.

In the forest proper the proportion of pines to oaks is approximately four to one. Both crab-apples and madrones are somewhat less numerous than the oaks, with alders still less common. Along the stream-channels the oaks are most numerous, with the pine, cherry, lancewood, and linden only sparsely represented.

Within a radius of three miles from Parícutin Volcano, much of the forest growth has been killed by the blanket of ash, which varies in thickness from a few inches to more than twelve feet depending on relative proximity to the volcano and on topographic position. Cultivated areas have been completely buried and ruined for agricultural purposes.

Preliminary results

(1) True fossilization, implying induration of the ash and mineralization of wood, has hardly begun.

(a) Wherever observed, the volcanic ash was generally unconsolidated; an occasional thin layer of very fine ash shows a slight degree of induration. Except in the uppermost six to ten inches of ash, moisture-content was high, despite the dry season, making the fine-grained ash quite compact and the medium-grained ash fairly compact; only the coarse-grained ash was found completely uncompacted. Imprints of leaves and other plant-remains were common only in the fine-grained ash, but the lack of induration of the ash made their recovery impossible.

(b) Buried trees showed no signs of mineralization; many upright trees, in fact, were still alive despite their burial by up to ten feet of ash. Fragments of buried limbs, cones, and branches showed only slight signs of decay. Buried leaves and pine needles were dry and crisp and only slightly carbonized in the uppermost ash layers, and moist and blackened by carbonization in the layers below. The greatest degree of decay was noted in the plant debris occurring in the ash layer just above the original soil layer.

(2) The processes of fossilization were highly selective, so that the plants were not equally susceptible to preservation.

(a) No recognizable remains of herbs were found preserved in the ash, despite their common occurrence in the forest. This absence is attributed to their fragile nature and to their habit of not shedding their leaves.

(b) The ash preserves an excellent record of both pines and oaks. The pines were represented by prodigious numbers of needles and many cones, catkins, and branches, in much greater abundance than might have been expected from the relative abundance of pines in the living forest. In one section of subaerial ash the ratio of pine needles to all types of dicot leaves was estimated as approximately 1000 to 1. Oak leaves were the most common type of dicot leaf encountered in the ash. In proportion to the remains of pines the buried oak leaves were less common than might have been anticipated. This is obviously due to the relatively greater output of needles per pine tree than leaves per oak. However, in proportion to other dicot leaves in the ash, the oaks were more numerous than would have been expected from the proportion of oaks in the living forest. This is interpreted as mainly the result of the tough, leathery texture of the leaves of both species of oaks, in contrast to the thinner and more fragile leaves of the remaining dicots. Of the latter, including crab-apple, madrone, cherry, lancewood, and linden, the ash has preserved only a meager record, considerably out of proportion to their common occurrence in the living forest.

(c) These observations are of significance to the paleobotanist, who attempts to infer the composition of the forest of which the fossils are the only record. It demands of the paleobotanist a knowledge of the physical characteristics of the species concerned and an appreciation of the processes involved in the burial and preservation of the various types of plant-remains.

(3) Plant-remains were well preserved only if buried close to their parent trees or shrubs.

(a) With rare exceptions the remains of pines, oaks, madrones, and alders were found well preserved in the ash only within 75 to 100 feet of their parent trees, regardless of the sedimentary process involved in their burial. The exceptions included the discovery of occasional oak leaves, fascicles of pine needles, and very rarely pine cones buried in excellent condition at distances up to 450 feet from their parent trees. It is believed, on the basis of observations in several situations, that the oak leaves and fascicles of pine needles were blown by gentle winds along the surface of the ash without injury and were subsequently buried by ash showers at the distances mentioned. No possible method was observed of transporting pine cones such distances without injury. It is suggested, on the basis of their occurrence in alluvial plain deposits, that the cones may have been rolled along a gently sloping surface by sheet-wash without appreciable abrasion or breakage.

(b) The buried leaves of crab-apple, cherry, linden, and lancewood were not well preserved, and often were difficult to identify, even within ten feet of their parent trees. Such leaves as were recovered and recognized were curled and twisted, and often torn and broken into shreds and fragments. Here again is a reflection of the relations between physical qualities of leaves and their chances for preservation and subsequent identification.

(4) Subaerial ash deposits contained more abundant and better preserved plant-remains than stream or lake deposits.

(a) Subaerial ash deposits are those occurring on upland slopes and divides, which were deposited almost exclusively by direct fall. In vertical sections exposed in several excavated pits, these deposits were seen to be alternating horizontal layers of fine to coarse ash, each layer of uniform thickness and grain-size throughout, with abrupt vertical changes in grain-size between adjacent layers. Occasional layers showed thin, wavy laminations. These characteristics are inferred to indicate periodic showers of ash, each shower depositing a layer of very uniform grain-size; the wavy laminations are attributed to wind-action during the dry season.

Plant-remains occurred in the subaerial deposits mainly in well-defined layers, interpreted to be seasonal. Between the plant-layers scattered plant-remains were fairly common within the ash layers, but pockets of plant-remains were rare. In general, the proportions of the species represented by buried plant-remains were in inverse ratio to the distances of the parent trees from the site of burial. Some species, however, as mentioned under (3) above, were not as abundantly represented as expected, even in sites only a few feet from the parent tree.

Essentially, all plant-remains buried in the subaerial ash deposits were in good or excellent state of preservation. All leaves were found curled, however, though not as greatly as in the stream deposits. The majority of the leaves were unbroken, reflecting little or no transportation before burial. The occasional torn or broken leaf is interpreted as having been damaged by wind transport from more distant trees. Pine needles were mainly unbroken and often still in their original clusters; delicate pine catkins were usually found undamaged. All in all, it was evident that both ash and plant-materials had been deposited gently, with little or no damaging transportation by strong winds or running water.

(b) Stream deposits of ash in the area are of two types, alluvial plain and valley-fill. The alluvial plains cover the formerly cultivated slopes between stream channels and the bases of steeper hills. Excavations showed the ash layers to be irregularly stratified, lenticular in part, and occasionally cross-bedded. Some layers were of uniform thickness and dipped uniformly down-slope. Grain-size was fairly uniform within layers; medium-grained ash was dominant, coarse ash fairly common, and fine ash rare.

Plant-remains in the alluvial plain deposits were observed to be less numerous and in worse condition than those in any of the other deposits studied. They were found both as widely scattered individual remnants and as occasional small pockets. The scattered remains, believed to be wind-blown, were in better condition than those in pockets, which were mainly broken fragments. Pine needles were less damaged than were the broad leaves of dicots. It was found that the proportional representation of different species was not as closely related to distances from parent trees as to the strength of the plant-remains against abrasion and breakage by water-transportation. Well preserved plants were not common in any case, and were very rare beyond 100 feet from parent trees. The exceptions were the few pine needles, oak leaves, and rare pine cones previously mentioned under (3).

Valley-fill deposits in the area are a result of the overloading of youthful streams by the immense supply of volcanic ash. Many stream valleys have been almost completely filled by ash and subsequently re-excavated in part by wet-season stream erosion, resulting in the development of vertical walls of ash standing above the present valley bottom. These natural exposures showed the ash layers to be very irregularly stratified, mainly lenticular, and often cross-bedded. The layers of ash were generally thicker than in other types of ash deposits and more uniform in texture. Fine ash was rare except at the surface, where it was brought in by wind.

As observed in excavations and in natural exposures, the plant-remains buried in the valley-fill deposits were fairly numerous and were an unusual mixture of plants in good condition and in poor condition, mainly in pockets. Scattered remains were common and discontinuous layers were noted in several instances. Pockets of coarse ash were usually barren of plant-remains, though occasionally they were filled with numerous highly abraded and broken leaf fragments, twigs, and acorns. Plants in the medium-grained ash were usually in a better state of preservation. Relative abundance and physical condition of buried plant-remains showed the same relation to distances from parent trees as was noted in other types of deposits. The mixture of poorly-preserved specimens along with well-preserved specimens is believed to indicate that some of the plants were transported a considerable distance before burial, resulting in abrasion and breakage; other plants were buried more rapidly and consequently suffered less from transportation. Oak leaves, somewhat curled, but intact, were common in the ash. Pine needles were also common, mainly broken but occasionally undamaged and still in fascicles. Some of the plant species, particularly crab-apple, cherry, and linden, were very rarely encountered, regardless of proximity to parent trees; the few specimens recovered were invariably tightly curled or twisted.

(c) Lake deposits were studied at only two sites, both in craters of extinct cones within a mile of Parícutin Volcano. Shallow, standing water was reported by natives to have been present in both craters during the rainy season. This was amply corroborated by the characteristics of the ash deposits. Excavations made near the middle of each crater-lake basin showed the ash layers to be mainly thinly-bedded, horizontal, and fine-grained. Individual layers were of uniform thickness; lenticular beds and cross-bedding were conspicuously absent. Some of the fine ash was claylike in texture in the presence of abundant water. Plant remains were not as common as had been expected, and were chiefly scattered rather than in well-defined layers. A slight concentration of plants was noted in the medium-grained ash which lay just above and below the fine clay-like layers. These concentrations are believed to be seasonal, namely pre- and post-wet season. The fine claylike ash contained only scattered pine needles; these layers are interpreted as deposits of the wet-season, during which time only pine needles were being supplied by the adjacent forest-growth. Buried plant-remains were generally well preserved; all leaves recovered were slightly curled and pine needles were mainly unbroken. The absence of flat, uncurled leaves, of the character generally expected in lake deposits, is explained by the fact that the trees in the vicinity produce only curled leaves, which were tough and leathery enough not to flatten out when immersed in standing water. Abundance of species represented by buried plant-remains was, as elsewhere, dependent upon distance from parent trees except for crab-apple, which was extremely rare in the deposits despite its presence in abundance in the nearby forest.

(5) Plant-remains in the subaerial deposits are the most likely to be destroyed by future erosion. On every hillside and divide observed in the area, stream gullying has already begun to remove the subaerial deposits. This seems to indicate that subaerial deposition has diminished, at least since the last wet season. Following the cessation of eruptive activity of Parícutin Volcano in the near future, it seems likely that the blanket of subaerial ash will soon be essentially removed, since it covers the summit- and slope-areas where stream erosion is most active. The only escape of the subaerial deposits from such a fate would appear to be their burial by lava flows, which seems unlikely in view of their topographic position and the diminution in the extrusive activity of the volcano. From the paleobotanical point of view, it is unfortunate that the deposits containing the best and most numerous plant remains are also the most likely to be destroyed.

(6) The best ultimate plant preservation, if any, is likely to be in valley-fill ash deposits buried by lava. Because of the influence which topography exerts on the spread of lava flows, the valleys in the Parícutin area were among the first of the land areas to be covered by lava. Before burial by lava many, if not all, of the valleys were filled by ash deposits, presumably containing plant-remains similar to those observed in the valley-fill deposits beyond the present limits of the lava. Following the cessation of volcanic activity in the region, it seems probable that streams will be forced to follow new courses rather than re-excavate old valleys through their resistant covers of lava. Other ash-deposits in the area are either on upland areas or slopes and thus are not likely to be buried by lava or to be spared from rapid removal by erosion. It therefore seems probable that fossil plants are most likely to be recovered in the future in the lava-covered valley deposits. The only other favorable sites for the survival of plant-remains would be lowland lake basins, which unfortunately are not present in the area adjacent to the volcano.

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APPLICATION OF STATISTICAL THEORY TO MEASUREMENTS OF VELOCITY AND SUSPENDED SEDIMENT IN RIVERS

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Abstract--To obtain a proper mean measure of velocity or suspended sediment-concentration in a turbulent stream, it is necessary to make observations or take data over a period of time because of the fluctuating nature of the measured quantity. Measurements of velocity with vane-type current-meters, and sediment-concentration determinations by sampling techniques are the important examples of the problem to be considered: namely, over what period of time must a measurement be made in order that a desired accuracy can be obtained for the mean value of velocity or sediment-concentration, and on what factors does this necessary time depend. The purpose of this paper is to apply the statistical theory of random sampling to the solution of this problem.

General theory--It will be assumed that the velocity, U, and suspended sediment-concentration, C, at any instant in a turbulent stream fluctuate about their mean values in accordance with the law of normal error. Experimental evidence indicates that this is true for velocity and there is every reason to believe that this must also be true for sediment-concentration. In the general analysis let x be the fluctuating quantity and $\bar{x}$ the true mean value. The theory of random sampling is developed for discrete variables; however, in this problem the velocity and sediment-concentration are continuous variables with respect to time. The parameter which completely characterizes the intensity of flustuation, when the fluctuation varies according to the law of normal error, is called the standard deviation and is defined as in equation (1).

$$\sigma_x = \sqrt{\overline{(x-\bar{x})^2}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

(where the bars indicate arithmetic mean values). The continuous variable x will be changed to a discrete one by defining x as the measure of the fluctuating quantity during a small time-interval Δt, where Δt is such that any further reduction in its value will not change σ_x. In other words, Δt must not be so large as to cause the peak-values of the fluctuations to be ironed out.

The general problem is to find the number, N, of Δt values (for example, size of sample or, more exactly, length of time of measurement) required to give a mean, $\bar{x}'$, which will not be different from the true mean, $\bar{x}$, by any pre-assigned percentage. It will be assumed that the true value of σ_x is known. The statistical theory then states that the sample means, $\bar{x}'$, will be normally distributed about the true mean with a standard deviation equal to ($\sigma_x/\sqrt{N}$) where N is the number in each sample. The so-called error in the sample mean is then $(\bar{x}'-\bar{x})$ and this is made dimensionless by letting

$$s = [(\bar{x}'-\bar{x})/\sigma_x/\sqrt{N}] \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

$$\text{or} \quad s = [(\bar{x}'/\bar{x}-1)\sqrt{N}/(\sigma_x/\bar{x})] \ldots \ldots \ldots \ldots \ldots \ldots (2a)$$

The probability, P, that any sample of N values will have a mean which will be within an interval s of the true mean is given by equation (3).

$$P = 2\int_0^s \phi(s)ds \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

where s is given by equation (2a) and $\phi(s)$ is the normal-error function. Values of the probability-integral in equation (3) can be found in tables. Equations (2) and (3) can be used to solve the following problem: What must N be in order that the probability be 0.95 that the value of $[(\bar{x}'/\bar{x})-1]$ will be 0.04 or less, if it is known that ($\sigma_x/\bar{x}$) is equal to 0.20? From tables of the normal probability-integral as in equation (3), it is found that $s = 1.96$ for $P = 0.95$. Then from equation (2a) we get $N = 96$. If our value for time-increment Δt, as previously defined, was one second, then the total sampling time should be at least 96 seconds if the conditions of the problem are to be met.

The above ideas will now be applied to velocity-measurement by current-meters and to the sampling of suspended sediment.

Velocity-measurement--Before the above principles can be used in connection with determinations of velocity in turbulent streams, the values of the time-increment, Δt, and the standard deviation of the velocity, σ_U, must be known. Certain experimental data [see 1 of "References" at end of paper] and analyses have indicated the general order of magnitude of $(\sigma_U/\bar{U})$ where $\bar{U}$ is the stream-velocity in the flow-direction at any particular point. This ratio is largest near boundaries (for example, the river bottom) and gradually decreases with distance from the boundary. For rivers a maximum value between 1/3 and 1/4 would be reasonable.

The time-increment Δt to be used in this analysis is subject somewhat to personal judgement; however, it is related to the scale of the turbulence present, that is, size of the eddies. Let L be equal to the mean size of the eddies present, then the mean value of the period, considering cyclical fluctuations, is equal to $(L/\bar{U})$. The value of Δt will then be some fraction of this period, as expressed in equation (4).

$$\Delta t = (kL/\bar{U}) \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

The author suggests that k be about 1/5. The scale of the turbulence L will be proportional to the stream-dimensions. It is smaller near the bottom and surface and reaches a maximum somewhere above mid-depth. For rivers the maximum value can be taken as a fraction of the depth. Experimental evidence indicates that the largest mean eddy-scale in a stream cross-section will be about 0.1D where D is the depth of river. Thus we have as a good estimate for Δt in equation (5).

$$\Delta t = (D/50\bar{U}) \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

To illustrate with a practical example: If D = 25 feet, $\bar{U} = 5.0$, and $(\sigma_U/\bar{U}) = 1/4$, how long a time should a current-meter reading be taken in order that the probability be 0.95 that the ratio of measured mean velocity to the true mean be between 0.97 and 1.03. From equations (3) and (2a) we find that N = 266. From equation (5) $\Delta t = 0.1$ sec. Therefore, the time of measurement should be at least 26.6 seconds. If the probability be 0.98 that the above accuracy be obtained, then the total time should be 37.7 seconds. In other words, an accuracy of three per cent can be secured with about a half-minute measurement. However, if an accuracy of one per cent is desired with a probability of 0.98, then the total time should be at least 340 sec, or almost six minutes. Note that the time of measurement varies as the square of the accuracy desired. Also, for comparable accuracy, the time of measurement should be directly proportional to the depth of river. Certain velocity-fluctuation data obtained with the PRICE current-meter in the Mississippi River [2] indicate that the above time-of-measurement figures are of the correct order of magnitude for the specified accuracy.

Suspended sediment sampling--Before any analysis can be made of the time necessary to obtain a correct measurement of suspended material at a point in a turbulent stream, it is necessary to know how the sediment-concentration varies with time at a point in a turbulent water-stream. Under conditions of equilibrium, the equation (6) relates the sediment carried upwards by the turbulence to that dropping down due to gravity.

$$\overline{Cv} = w\bar{C} \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where C is the sediment-concentration at any instant, $\bar{C}$ the mean concentration, v the fluctuating vertical-velocity component, and w the fall velocity in still water of the sediment-size being considered. Let $C = \bar{C} \pm c$, where c is the fluctuation in sediment-concentration above or below the mean value. Then

$$\overline{(\bar{C} \pm c)v} = \overline{\bar{C}v} + \overline{cv} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

The first term on the right is equal to zero since $\bar{v}$ is zero, and so equation (6) can be written as in equation (8).

$$\overline{cv} = w\bar{C} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

The fluctuation in sediment-concentration, c, is correlated to the vertical-velocity component, v, because when v is upwards (+) c is also positive, since the upward current is bringing up sediment from a region of higher concentration, and when v is downwards (-), the reverse is true in regard to c. In statistics such correlation is expressed by use of a correlation-coefficient r as in equation (9).

$$r = (\overline{cv}/\sqrt{\overline{c^2}}\sqrt{\overline{v^2}}) \ldots \ldots \ldots (9)$$

We then have, by substituting in equation (8)

$$(\sqrt{\overline{c^2}}/\overline{C}) = (w/r\sqrt{\overline{v^2}}) \ldots \ldots \ldots (10)$$

Let the ratio $(\sqrt{\overline{v^2}}/\overline{U}) = m$, then

$$(\sqrt{\overline{c^2}}/\overline{C}) = (w/rm\overline{U}) \ldots \ldots \ldots (11)$$

The value of m will vary with distance from the boundary; however, in general its value is somewhat less than $(\sqrt{\overline{u^2}}/\overline{U})$ which we stated reached a maximum of about 1/3 to 1/4. A good estimate of the maximum value of m is 0.20. Since we lack any definite information regarding the value of r, we will probably not be too far off if we let it equal unity, that is, there being perfect correlation between c and v, which is quite logical. Thus it is seen that the relative fluctuation in sediment-concentration $(\sqrt{\overline{c^2}}/\overline{C})$ is proportional to its velocity of fall, and inversely to the mean water-velocity. The latter fact is quite interesting and somewhat unexpected; however, it can be explained by the fact that with lower velocity the mixing is not as thorough and, therefore, relatively greater fluctuations in sediment-concentration can be expected.

Applying equation (11) to a practical problem, determine the necessary sampling time of having an error of three per cent with a probability of 0.98 for a sediment having a velocity-fall w equal to 0.1 foot per sec, where $\overline{U} = 3$ feet per sec, and D is 25 feet. Let $r = 1$ and $m = 0.2$ The value of $(\sqrt{\overline{c^2}}/\overline{C})$ is then 0.167. Using equation (2a) we find that $N = 169$. Since Δt, from equation (5) is 1/6 sec, then the total sampling time should be at least 28 seconds in order to obtain the accuracy indicated.

Present-day suspended load samplers and sampling techniques used in the field, in general, take samples for very short time-intervals. From the above analysis we must conclude that in such cases the probable error in the mean concentration obtained is undoubtedly quite large, especially for the larger-size sediments.

Conclusions--Application of the statistical theory of random sampling to the problems of water-velocity measurement in rivers by use of current-meters and suspended load determinations lead to the following conclusions:

(1) The time necessary for measurement of water-velocity to obtain any desired accuracy with any degree of certainty is proportional inversely to the square of the per cent of accuracy desired and directly to the square of the intensity of turbulence; it also varies directly as the stream-depth and inversely as the mean velocity.

(2) The above statement also holds for measurement of suspended sediment, except that the relative intensity of sediment-concentration fluctuation comes into the problem, which is proportional directly to the fall-velocity of the sediment and inversely to the mean water-velocity.

(3) The analyses made can be reduced to the approximate expressions of equations (12) and (13) for the necessary time of measurement (in seconds) for velocity and suspended sediment, respectively.

$$T_{\overline{U}} = (D/200\overline{U}p^2) \ldots \ldots \ldots (12)$$

$$T_{\overline{C}} = [(2w^2D)/\overline{U}^3p^2] \ldots \ldots \ldots (13)$$

In the above equations (12) and (13) p is the desired limit of accuracy, expressed as the ratio of measured mean to true mean minus 1.00. The probability that the desired accuracy will be obtained has been taken as being about 0.95, which is a reasonable degree of certainty. The velocity-fluctuation ratios, $(\sqrt{\overline{u^2}}/\overline{U})$ and $(\sqrt{\overline{v^2}}/\overline{U})$, were taken as 0.25 and 0.20 respectively, which are about the maximum values to be expected in ordinary channel-flow where the turbulence is produced solely by bottom and side friction.

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DISCUSSION

LORENZ G. STRAUB (Room 6402, 350 Fifth Avenue, New York 1, N. Y., May 20, 1945)--In determining river-discharges with reasonable accuracy by current-meter velocity-measurements, it has long been recognized that sufficient time-interval must be allowed for each observation of velocity. The reason for making a current-meter observation for a duration of as much as a minute or more, however, has not always been associated with velocity-pulsations in the stream, but probably more frequently, at least until of late, with the precision in establishing the time-interval over which the observation is made. An analytical approach such as the author presents is therefore a welcome contribution in providing a clearer conception of the importance of taking into account velocity-pulsations in establishing the time-interval required to obtain good mean values of the velocity past a particular point, aside from inherent personal shortcomings in timing the duration of observations.

It is also apparent that thinking has been somewhat confused on the best method of gathering representative samples of suspended sediment-laden water for obtaining accurate information of the quantity and mechanical composition of the suspended load of the river. Here the need for taking a sample at a point over an appreciable time-interval could not be influenced by the same reasoning as that which originally prompted making measurements of velocity over a time-interval. The all-important reason for taking a sample which provides for the integrated averaging of suspended load at a point over a time-interval is that in most rivers pulsating-flow results in continual change of the concentration and character of suspended sediment at any particular point; this is especially true for the coarse particles --of diameter greater than 1/16 mm--and near the river-bed. In the case of the more finely divided material--particles smaller than 1/16 mm--the pulsating-flow does not have as great influence on the concentration of suspended load.

Merely a superficial observation of a stream heavily laden with suspended sediment emphasizes the importance of making suspended load samples include material gathered over an appreciable time-interval. Thus it will be observed that the water has a definite mottled appearance, frequently punctuated by "boils", of distinctly different color from the surrounding stream, rising to the water surface. Probably if one were to watch the surface of a river of this character with some care and discernment, and with the aid of a stop-watch, one might arrive reasonably well at the time-interval which would be required in gathering a suitable integrated average specimen of the river's suspended load. One would surely conclude that a considerable time-interval is required.

The writer has had occasion to make observations of the suspended sedimentary load of rivers under various conditions and with samplers gathering the specimens at various rates, from instantaneously to a period of as much as a minute or more. The specimens were analyzed both for total quantity of solids in parts per million and the amounts of various-size grades of sediment. Much of this work was done particularly on the Missouri River. Instantaneous samples were always found to be erratic, particularly in the amount of coarse material, varying greatly for successive specimens taken from the river at the same point. On the other hand, specimens taken over considerable time-period gave remarkably consistent results, both with reference to quantity of material and gradation into sizes. A good example of the latter was presented a number of years ago by the writer before the Section of Hydrology [see 1 of "Reference" at end of discussion].

It is, of course, important in taking an integrated sample to recognize that a change in velocity or direction of flow in the vicinity of the intake of the sampler will influence the nature of the sample. This is particularly true with reference to the coarser particles because the concentration of these is more definitely influenced by retardation of flow, change in degree of stream-turbulence, and centrifugal action resulting when the water is forced to change its direction of flow upon entering the sampler. In most instances, however, it is not likely that these influences will be nearly as great as deviations which take place at the point of observation as reflected by instantaneous sampling as compared to integrated sampling.

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A. G. ANDERSON (3625-22nd Avenue South, Minneapolis 7, Minnesota, May 20, 1945)--This interesting application of statistical methods to the measurement of velocity and suspended load in streams not only provides equations for determining approximately the time required to obtain a mean value but also provides helpful insight into the effects of the physical properties of the stream and sediment upon the statistical measures which characterize the turbulence. The relationship of the various factors as they affect the turbulent flow and govern any representative times as demonstrated by the author are probably of equal importance with the final equations.

For the sake of clarity it should be mentioned that the accuracy, as such, of the mean of a sample may depend upon factors other than, as well as in addition to, the turbulent fluctuations of the stream. The accuracy as used in the paper as a measure of the departure from some mean assumes that the sampler, or device, is mechanically capable of measuring the true magnitude of the variable in the course of averaging its fluctuation. It is conceivable, in the case of suspended load samplers particularly, that the accuracy of the measurement is determined more by the limitations of the sampler than by the fluctuations of the sediment-concentrations. This is probably less true in the case of current-meter observations. The results given yield the time required for assurance to a certain degree that the measurement will not depart by more than a specified amount from some value whose magnitude is affected by the characteristics of the sampler or measuring-device.

For the reasons set forth in the paper, samplers of the time-averaging type, that is, samplers which collect a sample over a longer period of time, are coming more and more into use and their use will probably improve the accuracy of the samples by allowing advantage to be taken of such an analysis as presented by the author, provided that the mechanical design of the sampler is adequate. The analysis provides some rational aids for this purpose in proportioning the parts of the sampler to meet the requirements for use in a given range of conditions.

NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 224, 248, 274, 297, 300, and 304)

NOTES

Research on ground-water conservation--The Engineering Experiment Station of Purdue University has recently initiated a project, entitled "Research on ground-water conservation." The studies included in the project are: (1) Quantitative determination of underground storage; (2) annual natural recharge of underground storage; (3) porosity and transmissibility of underground water; (4) artificial recharge of underground storage; and (5) variation of the underground water-table. The investigation will be limited in scope to an area of approximately seven-mile radius from Purdue University, West Lafayette, Indiana. Cooperating with Purdue University in the project are the Indiana Department of Conservation and the United States Geological Survey.

Water conservation in Indiana--The Indiana Flood Control and Water Resources Commission was created by the last General Assembly of the State to survey the water resources of Indiana in cooperation with Federal agencies for the purpose of protecting the State's water supplies and to alleviate or prevent floods. D. H. Harker, formerly chief of staff of the Ohio Water Supply Board, has been appointed Chief Engineer.

Arctic Institute of North America--The recently organized Arctic Institute of North America has carried its plans to the point that it expects to open headquarters, with a full-time staff, in a building on the campus of McGill University in Montreal. L. M. Gould has resigned as Acting Director and A. T. Washburn has been appointed Director, with Miss B. M. Bridge as Executive Secretary.

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(See also pp. 190, 203, 212, 216, 240, 302, 314, and 324)

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A NOTE ON MULTIPLE RAIN-GAGES

H. G. Fourcade

In a paper by C. L. WICHT [see 1 of "References" at end of paper] the author writes:

"The Fourcade gage will record more rain than is deposited on the ground. In strong wind when mist-particles are traveling nearly horizontal most of the time, practically no precipitation should be deposited on the ground. In such a case, the standard gages should record a negligible amount of rain, whereas the Fourcade gage may give relatively high readings."

These remarks show a complete misunderstanding of the functions and operation of a gage with vertical apertures. Such a gage merely records the horizontal components of the rainfall, apart from the vertical component recorded by an ordinary gage. It is obvious that the horizontal components, however large, will contribute nothing to the rainfall intercepted by a horizontal surface. On a slope, the total intercepted rainfall will be made up of the sum of the interceptions of each component by the receiving surface, but it is more convenient to take these together by means of formulas given in a paper by the writer [2]. As the formulas will apply to any similar form of rainfall-analyzer with vertical apertures, and the paper is not readily accessible outside South Africa, it may be useful to recapitulate them. Their proofs are so elementary that there is no need to repeat them here.

Let R_v, r_n, r_e, r_s, r_w be the respective catches per unit of area of an ordinary gage, with horizontal aperture, and four gages with vertical apertures facing north, east, south, and west. The vertical, northward, and eastward components of the rainfall are: R_v, $R_n = (r_n - r_s)$, and $R_e = (r_e - r_w)$. The direction from which rain is falling, reckoned from north in a clockwise direction is given by

$$\tan \bar{\omega} = (R_e / R_n)$$

The horizontal component R_h of the rainfall is given by

$$R_h = (R_n / \cos \bar{\omega}) = (R_e / \sin \bar{\omega})$$

Its inclination, i, from the vertical by

$$\tan i = (R_h / R_v)$$

Finally, the effective rainfall received by a slope, over its horizontal area, is given by

$$R_s = R_v + R_v \tan \alpha \tan i \cos (\beta - \bar{\omega})$$

where β is the aspect of the slope, reckoned from North in a clockwise direction, and α its greatest inclination. When i exceeds 45° it may become preferable to substitute $R_h \cot i$ for R_v and write

$$R_s = R_h \cot i + R_h \tan \alpha \cos (\beta - \bar{\omega})$$

If then $i = 90°$, and $\alpha = 0$, cot i and tan α both become zero, and $R_s = 0$, so that it is incorrect to state that the multiple vertical gage may indicate some rainfall on a horizontal surface when none is collected by a standard gage.

In the original paper, tan i was derived differently, but the above presentation is better because it gives, without additional computation, R_h, which may then be used, at need, in the alternative R_s-formula.

The observations presented in Table 1, communicated by Dr. WICHT, were made at Jonkershoek, the locality of the experiments detailed in his paper already cited [1], with the multiple vertical aperture gage of which a figure (p. 596) is given.

Table 1--Rainfall-catch with Fourcade multiple aperture rain-gage at Jonkershoek Forest Influences Station, Jonkershoek, Stellenbosch, South Africa

Month	r_n	r_e	r_s	r_w	R_v	R_h	ω	i
1943	in	in	in	in	in	in	° ′	° ′
May	0.36	0	0	0.84	2.29	0.91	293 10	21 45
June	0.30	0.16	0.16	2.43	4.58	2.27	273 30	26 25
July	5.81	0.16	0.24	4.21	7.41	6.89	324 00	42 55
Aug	6.20	0.18	0.28	5.23	7.17	7.78	319 30	47 20
Sept	4.42	0.02	0.02	1.02	2.64	4.51	347 10	59 40
Oct	2.16	0.06	0.08	2.00	3.37	2.84	317 00	40 10
Totals	19.25	0.58	0.78	15.73	27.46	23.89		
						Averages	320 23	39 43

To meet the exceptional case of mist-particles traveling nearly horizontal in high winds, the gage was made with a widening chamber, followed by baffle-plates, but in ordinary cases the much simpler construction shown in Figure 1 would probably serve equally well.

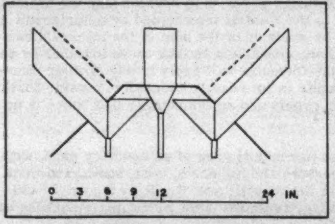

Fig. 1--Cross-section through simplified multiple rain-gage

Four elbow-tubes are disposed at 45°-inclination on a truncated-pyramid base. Their vertical apertures, cut at 45° to the tubes, are set to face the four cardinal points of the compass, and their shorter arms are left open sheltered by the base. An ordinary gage is added centrally. The area of the aperture of each gage is ten square inches. The sloping tubes are made of material with an internal diameter of three inches and the upright one of three and one-half inches. To give exactly ten square inches the diameters should be 3.00052 and 3.56826, to which they can be brought with sufficient approximation by beveling the rims internally, then externally to narrow the edges. The small diameter of the central gage makes it possible to incorporate, between the sloping tubes, a proportionally small wind-shield, indicated in Figure 1 by dotted lines.

The sloping gages cannot be shielded, and do not need to be because it is only when the wind blows from the neighborhood of one of the cardinal points that it meets any of the vertical openings at a small angle and may cause turbulence similar to that which affects the catches of the upright gage. And even when this happens any resulting error would be limited to that in the small catch of the one vertical opening at a small angle to the wind, and would be negligible in comparison with the rest of the catches of all the gages for a day or period.

The construction of the tube-gage was begun but not completed because war conditions would have prevented arranging for continued observation.

To operate correctly, any multiple gage should be installed only on a plain, or level hill-top where the wind blows more or less horizontally.

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PREVENTION OF SEEPAGE IN FOUNDATIONS FOR DAMS

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Abstract--The theory of seepage in foundations for dams has been treated in numerous articles and publications. The purpose of this paper is not to discuss such theoretical considerations, but to present briefly a number of instances which the writers have encountered in their professional practice, where seepage had actually occurred in existing foundations for dams or has threatened to occur, and likewise to discuss the actual measures which were taken to prevent this seepage or to control it to such an extent that it did not endanger the safety of the dam structure.

Foundations for dams: General considerations--This paper treats, not with the theoretical considerations of causes of seepage in foundations for dams, but with the practical engineering and construction approach to the control of seepage through such foundations, based upon a few of our personal observations and experiences on projects with which we have been connected. Due to limitations of space, no attempt has been made to cover the subject fully.

The foundation of a dam must have adequate bearing power to provide stable support for the superimposed dam-structure under all conditions of loading and must be sufficiently water tight, or capable of being made so, to prevent seepage under the dam or to reduce it to safe limits.

As the more favorable dam-sites are being rapidly utilized, engineers, in the construction of safe and economical dams at sites far from ideal as to topography and geological conditions, are called upon to exercise more and more ingenuity in producing sound foundations.

The type of dam to be built at a given site will depend upon materials available for construction and upon foundation-conditions encountered, as well as upon general economic considerations. The selection of the type of dam, its design to meet existing foundation-conditions, and the proper preparation of deficient foundations must be based upon sound judgment and mature experience.

Surface investigations--After the preliminary investigation of the dam-site has been made, and the general type of dam to be built has been selected, thorough geological studies must be made. These usually begin with a review of geological maps, reports and data available in publications of the United States Geological Survey, United States Bureau of Mines, State Geological Departments, and other public and also private agencies, and are followed by a careful field-examination in which all rock-exposures are classified and mapped as to age, origin, character, and structure. The dip and strike of sedimentary beds, the shape and magnitude of folds together with the location, dip and strike of all faults, and the direction, extent, and width of all crevices must be determined.

Sub-surface investigations--After surface conditions have been completely investigated, subsurface conditions must be determined with much care and in the greatest detail to ascertain the character of the underlying rock, its probable bearing-power, the steps necessary for the prevention or reduction of seepage, and other special treatment necessary to meet the requirements for a sound foundation.

Unconsolidated sediments are usually tested by earth-augers, open pits, caissons, shafts, well-drill holes, and wash-borings. Geophysical methods, both seismic and electrical, are also used where the overlying sediments are deep, and it is necessary to know depths to rock in order that contours of underlying rock can be mapped.

Consolidated or metamorphosed sediments and volcanic rocks are usually tested by pits, shafts, tunnels, diamond-drills, and Calyx shot-bit core-drills.

Diamond and Calyx drill-cores give a continuous, accurate, and permanent record for determining the nature, extent, and structure of the rock drilled through. Diamond-drill cores for foundation-exploration vary in diameter from 1-1/8 to 4 inches, and Calyx cores vary from 4 to about 8-5/8 inches in ordinary drilling. On some of the recent larger dams, Calyx shot-bit holes 30 inches to

36 inches in diameter have been drilled in the foundation, down which engineers and geologists were lowered to study the rock-section exposed.

In core-drilling, the larger the diameter of the core removed the easier it is to interpret the geologic structure encountered. Seldom will the length of the core recovered represent 100 per cent of the hole drilled. To attempt to visualize the character of that portion of the foundation-material for which no core is recovered and upon this inadequate information design the dam, making an assumption that any weakness of foundation later discovered can be remedied, is hazardous and may lead to serious difficulties and involve a greatly increased cost of construction.

Foundations on unconsolidated sediments--When unconsolidated sediments form the foundation of a dam, it is important to determine not only the depths at various points to impervious strata or bedrock, but to put down a sufficient number of holes so that a complete record of all soil-formations occurring in the foundation is secured, if steps necessary to prevent or reduce seepage through the foundation are to be planned in advance of construction. It is also advisable to have tests in the field or laboratory made to determine the permeability of the material encountered in the foundation-explorations.

The extent to which the probable seepage through the foundation-material should be prevented will depend both upon the value of the water lost through seepage and upon the possibility of endangering the safety of the structure. If water is conserved through storage and its value in sale or use is great and the water lost by seepage cannot be recovered, it may prove advisable to expend considerable sums to prevent its loss. If, however, storage is created for flood-control, or if the seepage-waters can be later recovered, seepage is not in itself objectionable unless it affects the safety of the structure.

If even a slight loss of water is objectionable from an economic standpoint, a cut-off wall usually at the upstream face of the dam should be carried down to rock or to an impervious stratum. Where the depth is too great for proper handling of a core-trench, interlocking wood, steel, or concrete sheet-piles may be substituted or the depth of the cut-off wall increased by their use.

The usual purpose of a cut-off wall which does not penetrate to impervious material is to lengthen the path of percolation or seepage over which the water must travel from the upstream to the downstream toe of the dam, thereby flattening the hydraulic gradient and reducing the velocity below a point at which the finest material occurring in the foundation will not be carried out of it by flowing water.

If neither of the above described methods appear to be practical, an alternate method is to lay, on the stream-bed and over the abutments, if necessary, a blanket of compacted material connecting with the impervious section of the dam and extending for some distance upstream. This blanket should have a thickness of three to ten feet, depending both upon the head of water to which it will be subjected and upon the material constituting the foundation.

In the West, at a municipally owned earth-dam 37 feet high and built upon valley-fill, a leak developed near the downstream face after the reservoir had been in operation, which in time assumed alarming proportions. The water in the reservoir was lowered and holes were drilled in the area where the leakage was occurring, disclosing a lenticular body of gravel in the foundation which had not been discovered in the original explorations of the dam-site. Through the area of the leak, 60-foot interlocking wood piling were jetted into place, parallel to the axis of the dam. This effectively stopped the leak. The jetting was done with water under pressure of 300 pounds per square inch.

A California dam, 85 feet high, with 700,000 cubic yards of material in the rolled fill, was built on glacial moraine. The slope of the section of the rolled fill was 2 to 1 on both upstream and downstream faces. In the abutments, lenses of sand occurred, none of which, fortunately, extended entirely through the abutments. To increase the length of the path of percolation through the abutments and the base, and also to seal off the sand-lenses in the abutments, a cut-off trench was excavated at the upstream face of the dam and a blanket of impervious material placed upstream from the dam and on the abutments. This cut-off trench varied from 25 to 30 feet in width and was about 20 feet deep. It was filled with an impervious compacted material and upstream from the dam about 300 feet and on the abutments, a rolled-fill blanket ten feet in thickness was placed. This construction increased the path of percolation to eight times the height of the dam and practically stopped seepage. On the outside of the rolled fill-section of the dam, waste material was placed by end-dumping from trucks, and a bulldozer was used to push the material over both the upstream and downstream faces of the dam. The larger rock rolled to the bottom of the dam giving a free drainage-pile of rocky material. The slope of the final section varied between 4-1/2 to 1 at the base and 2-1/2 to 1 at the top of the dam.

One of the best illustrations of a dam built on a foundation of sand and silt is the Laguna Dam, built for diversion on the Colorado River 12 miles upstream from Yuma, Arizona, some 40 years ago by the United States Bureau of Reclamation. This dam is of the weir type, the first to be constructed in this country, and is 4,780 feet in length between rock-abutments and 19 feet in height above stream-bed, with a maximum height of 40 feet. It is used to divert the water into irrigation-canals on the Arizona and California sides of the River. The dam-structure is traversed longitudinally by three concrete cut-off walls extending between the rock-abutments, each wall being five feet thick and extending from the top of the dam to well below the river-bed. The upstream cut-off wall was placed at the crest of the dam, and rested upon a row of six-inch wooden sheet-piling, 12 to 32 feet long, driven across the entire length of the dam for the purpose of cutting off the seepage. The second wall was 57-1/2 feet downstream from the first, and the third was placed 93-1/2 feet downstream from the second. The dam has a base of 166 feet, with a slope downstream from the crest of 12 to 1. This dam is the overflow-type, and the head against it is not great, but the use of the cut-off walls and the sheet-piling increased the length of the path of percolation sufficiently to reduce the underflow to a safe minimum.

Consolidated sedimentary-rock foundations--Rocks such as limestones which may have large solution cavities, or rocks in which seams or veinlets of easily soluble material are apt to occur, are extremely unreliable as a foundation-material. A California city built a hydraulic and rolled-fill dam on a valley-floor. The west abutment was a conglomerate sand rock, and the east abutment a steeply dipping east-west anticlinal fold of diatomaceous shale which disappeared beneath the valley-floor a short distance west of the east abutment. The lower 70 feet of the hydraulic fill was built of material obtained from the area of the reservoir. The next 20 feet was of diatomaceous shale secured from the east abutment. In later years the dam was raised several times to an ultimate height of 132 feet by adding rolled-fill sections, a great deal of the material coming from the east abutment.

The westerly dipping diatomaceous shale of the east abutment, to a depth of approximately 50 feet below the crest of the dam, contained seams and veinlets of gypsum. This shale overlaid several feet of a hard siliceous limerock below which was a strata of dark thinly laminated tight siliceous shale which contained little gypsum.

The diatomaceous shale was reasonably resistant to the circulation of water, but bedding-planes and broken strata afforded an opportunity for water to circulate through the strata, and come in contact with the readily soluble gypsum, which it dissolved and carried away in solution, causing a honeycombing and a resultant weakening of the rock-structure. As a result of this weakening of the rock-structure, the dam settled in the area near the east abutment. There was also evidence that the gypsum in the shale from the east abutment, which was used in the dam, was honeycombed, because, when the water in the reservoir was lowered, a general settlement took place throughout the entire structure. There was also a slight shifting of the dam upstream. An intensive grouting-campaign was undertaken, starting in the diatomaceous shale of the east abutment. To test the efficiency of this grouting as a means of stabilizing the rock in the east abutment by cementing the rock-fragments from which the gypsum had been removed by solution, a shaft 20 to 25 feet deep was sunk in the grouted section of this abutment. It was found that the grout had filled all of the openings from which the gypsum had been dissolved, and had completely restored the rock. Grouting was then continued westward along the axis of the dam. All of the holes drilled were continued well down into the dark thinly laminated tight siliceous shales.

A general discussion of the grouting-program will not be undertaken, but it is interesting to note that in the case of two holes, drilled 15 feet apart, the first, drilled 160 feet from the east abutment, took 4,537 cubic feet of grout, of which 3,680 cubic feet were placed at a depth of 60 feet in the diatomaceous shale of the abutment and 40 feet below the contact with the rolled fill. The grout from this hole came through cracks in the slab on the upstream face of the dam 100 to 200 feet east of the abutment and 60 feet north of the axis of the dam, and continued to come out after the pressure was released. This indicated that the grout also filled cavities in the dam. The second hole, 15 feet away, took 6,334 cubic feet of grout, 800 cubic feet between depths of 51 to 67 feet in the abutment and 5,534 cubic feet at 101 feet in depth. Grout from this hole also came through the concrete-face slab under water, 215 feet west of the east abutment and 165 feet upstream from the axis. This hole was plugged with heavy grout at 20 pounds pressure. A third hole, located five feet from the first hole, was grouted after operations on the two holes had been completed, and took only 142 cubic feet of grout, of which 30 cubic feet was sand. This grout was placed at a depth of 103 feet in the dark shale of the abutment. The small quantity of grout used indicated that the grout from holes 1 and 2 had plugged the porous fill and rock-fractures, and the grout placed in hole 3 filled only the rock-fractures and openings along bedding-planes. In another of the test-holes, 300 feet west of the east abutment along the axis of the dam, an air-pocket which took several hours to exhaust, was tapped 20 feet below the crest of the dam. This indicated a porous condition of some of the strata in the rolled fill in which air had been compressed by grouting. The grouting reduced the leakage of water through the dam and foundations to a point of absolute safety.

Volcanic rock-foundations--The larger concrete dams, because of foundation-pressures involved, are usually constructed upon consolidated sediments or volcanic rocks of high bearing-power. Where seepage might occur through fractures, faults, or crevices great care must be exercised in exploring this type of foundation, to insure the location of all zones and planes of weakness, through which seepage might occur.

In dams built on this type of foundation, the cut-off wall is most important, since it not only keys the dam to the foundation but serves to prevent seepage of water through it. It is customary to excavate the trench for the cut-off wall entirely across the upstream face of the dam, continuing it up the abutments to the crest. The depth to which the cut-off trench should be excavated will depend upon the character of the rock encountered, but it should extend to fresh unaltered tight rock if possible.

After the foundation has been cleaned of all fractured and weathered rock, the average depth of the cut-off trench may not exceed ten feet, but we have known of cut-off trenches which followed a fracture line in granite to a depth of 50 feet, and at the Rodriguez Dam in Lower California, a fault along one of the abutments was mined out beneath the foundation to a depth of 300 feet and filled with concrete.

One of the writers was on the Board of Consulting Engineers for the contractors on a dam built in the Northwest where the exploration was made, using a diamond-drill bit which gave a small core with a low percentage of recovery. The agency designing the dam interpreted the results of the drilling favorably and assumed that good foundation-conditions existed. When the contractors drove the by-pass tunnel, they encountered a fault-zone of soft broken rock which continued into the foundation of the dam. After the coffer-dams had been completed, the river by-passed, and the excavation started in the river-bed in the area of the dam site, two faults were uncovered, one on the west abutment striking north and south along which the river had cut through the granite, and another, a continuation of the fault-zone encountered in the by-pass tunnel, an east-west fault dipping under the dam, parallel to the axis, and extending across the river-bed at the upstream face of the dam. This east-west fault, parallel to the axis of the dam, near the east-west contact of the sedimentary rock and the granite, carried about four feet of soft clay gouge on the foot-wall with parallel shear-planes across a distance of 40 to 50 feet. The north-south fault was a crushed mass of granite and diorite 8 to 25 feet wide, dipping west into the west abutment at an angle of 55°.

The contractors had built their batching plant high on the west abutment, and were fearful that a slide of the crushed material along the intersection of these two faults would endanger their plant. The existence of soft material in the fault-zones would also have allowed the seepage through them of water behind the dam which ultimately might have reached a large volume and endangered the safety of the dam.

The rock in the foundation in the area of the faults was so soft that the shovel could handle it without blasting. When it was determined that the foundation-conditions were not going to improve with depth, the lower 25 feet of concrete in the base of the dam was poured and a shaft left through it, after which the soft material in the fault-zones was mined out and the space back-filled with concrete. This erroneous interpretation of drill-cores, where small-diameter cores were taken and a low core-recovery occurred, caused a substantial increase in the estimated cost of the dam.

Grouting--Grouting of the rock in the foundation of a dam is standard practice for the elimination of seepage through the foundation, and to be effective should follow a carefully prepared plan. The grout-holes in a cut-off wall are usually drilled in two or more parallel lines, and the holes in the rows staggered so that a more effective grout-curtain is produced.

Usually when a hole has been drilled, it is thoroughly washed out and a test for loss of water under pressure is made. If a large loss of water indicates open seams or fractures, which take grout freely, some sand may be added to the grout until the hole refuses to take grout readily. To insure satisfactory results as much grout should be forced into the foundation as it will take.

When the water-test indicates that the foundation is fairly tight and the openings small, neat cement with varying amounts of water from 5 to 25 gallons per sack of cement are used. In rocks where openings are small, compressed air is often used to force the water back into the rock, and then the grout is forced in.

The maximum pressure to be used in grouting depends upon local rock-conditions. In a sedimentary rock with more or less horizontal bedding-planes, the grouting-pressures should be controlled so as not to lift the rock. Frequently, grouting is carried on at two or more depths; shallow grouting under low pressure in closely spaced holes to stabilize the upper rock-mass with deeper grouting at high pressures to stabilize the lower rock-mass.

Many attempts have been made to use bentonite, calcium chloride added to sodium sulphate, and other chemical combinations with cement in grouting, but it is generally agreed that neat cement or cement and sand with varying amounts of water give the best results as grout-mixtures.

When concrete is placed in a cut-off trench, vertical pipes are installed so that when the cut-off wall is completed, drilling of the grout-holes can be carried on from the top of the cut-off wall through them.

A rolled earth-filled dam 182 feet in height, in California, was built on a foundation of volcanic ash, which had been deposited in water and mechanically cemented by extremely fine material which would pass a 1,000-mesh screen. Difficulty was experienced in grouting the foundation. It was determined by test, using grout consisting of 25 to 30 gallons of water per sack of cement, that the only grout introduced into the volcanic ash was that which through pressure displaced the water in the openings in the rock.

In the foundation along the north abutment, as well as in the foundation, a number of springs occurred. Ditches were dug in the foundation and pipes placed therein to carry the spring water to a sump. When the ditches were collecting no water, the four-inch pipe was blocked up and the ditch filled with concrete. When, however, the ditch was collecting water, rock was placed in the bottom of the ditch, and the pipe was laid. Around and above it rock was placed and a four-inch thickness of concrete placed on top of the rock to fill the ditch.

All of the pipes led to a sump either upstream or downstream from the cut-off wall on the axis of the dam.

The problem of concreting off these springs after the rolled fill had been placed was solved in a very ingenious way. From each pipe-line a riser-pipe was run in the foundation to the abutment and carried to the surface through the fill in a rising-ditch in the abutment. These pipes came out of the face of the fill of the dam at a height of 72 feet above the foundation. This height gave the pressure under which the engineers in charge of construction felt necessary to concrete off these springs.

When they were ready to grout off the water, the grout-machine was connected in turn to each pipe at the sump and grout was pumped in it until it came out of the riser-pipe, then the valve on the pipe-line at the sump was closed. It was considered that under these conditions a complete shut-off was accomplished. After the fill was completed, several holes were put down through the fill to intersect these pipes. In many instances these pipes were intersected and pipe filled with grout was brought up in the core.

The rock on the abutment was of a somewhat different physical character, and vertical fractures up to 1-1/2 or 2 inches in width occurred. When tunnels were driven in on these fractures 20 to 30 feet, the fractures became tight and disappeared.

In the placing of the rolled fill in the dam, these vertical fractures in the abutments were covered by half-section of pipe (the pipe being cut longitudinally) held in place by cement mortar. The fill was placed around these pipes. When the fractures closed, the half-pipe was carried a length or two higher and then filled to refusal with grout. This effectively sealed off the fractures.

In general, it may be stated that when the foundation has been properly prepared and adequate precautions taken to prevent seepage, dams have been built on almost every type of material from silt to the hardest rock.

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(Manuscript received April 15, 1945; presented at Los Angeles Regional Meeting, February 27, 1945; open for discussion until March 31, 1945.)

NOTES AND PERSONALIA

NOTES

Corrigendum--The following omission has been noted in the Transactions of 1944:

Part VI, p. 1044, Figure 5 is incomplete as published as it omitted the data for 1942. The Figure is reproduced in full, below.

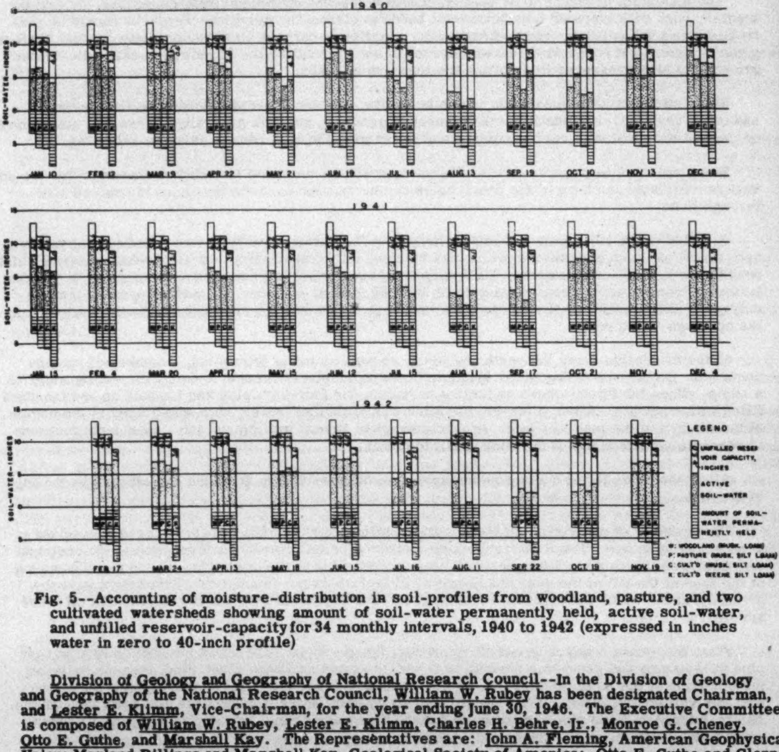

Fig. 5--Accounting of moisture-distribution in soil-profiles from woodland, pasture, and two cultivated watersheds showing amount of soil-water permanently held, active soil-water, and unfilled reservoir-capacity for 34 monthly intervals, 1940 to 1942 (expressed in inches water in zero to 40-inch profile)

Division of Geology and Geography of National Research Council--In the Division of Geology and Geography of the National Research Council, William W. Rubey has been designated Chairman, and Lester E. Klimm, Vice-Chairman, for the year ending June 30, 1946. The Executive Committee is composed of William W. Rubey, Lester E. Klimm, Charles H. Behre, Jr., Monroe G. Cheney, Otto E. Guthe, and Marshall Kay. The Representatives are: John A. Fleming, American Geophysical Union; Marland Billings and Marshall Kay, Geological Society of America; Otto E. Guthe and Glenn T. Trewartha, Association of American Geographers; Charles H. Behre, Jr., Society of Economic Geologists; L. H. Adams, American Ceramic Society; Monroe G. Cheney, American Association of Petroleum Geologists; J. F. Schairer, Mineralogical Society of America; L. W. Stephenson, Paleontological Society; Raye Platt, American Geographical Society; and William E. Wrather, United States of America. Members at large are William W. Rubey, W. Storrs Cole, and Lester E. Klimm.

National Geographic Institute of Costa Rica--Costa Rica has recently established a National Geographic Institute which will serve as a center for studies in geography and geophysics, and arrange for the preparation of official large-scale maps.

Transactions, American Geophysical Union Volume 26, Number II October, 1945

FORECASTING STREAM-FLOW OF THE SALT RIVER, ARIZONA

C. K. Cooperrider, H. O. Cassidy, and C. H. Niederhof

Abstract--In the Southwest, where water is the controlling factor in agricultural development, intensive efforts have been made to conserve and regulate stream-flow by means of storage-reservoirs. An example is provided by the chain of reservoirs on the Salt River in central Arizona. The regulation of these reservoirs could be enhanced considerably by some means of stream-flow forecasting. Consequently, a method has been developed whereby the spring-flow of the Salt River can be forecast with a reasonable degree of accuracy from the flow of a small tributary, Parker Creek, located in the Sierra Ancha Experimental Forest. Correlating the flow of Parker Creek from October through February with that of the Salt River from March through May, an equation has been developed which forecasts the March-May flow of the Salt River. In addition, an equation is given which expresses the error associated with any future forecast. The practical application of expressing the error is to give the possible minimum or maximum flow that might occur under selected odds. Using the Parker Creek data for the October-February period of 1944, a forecast was made for the spring-flow of the Salt River. The estimated or forecast-flow came within 2.2 per cent of the actual flow.

Introduction

Water is the limiting factor in agricultural development in the Southwest. Not only is stream-flow inadequate, but in most areas it is seasonal in character. Furthermore, the volume of flow fluctuates drastically from year to year. These factors have made it necessary to construct large reservoirs in an attempt to convert periodic and erratic stream-flow into the steady, dependable water-supply needed for power and irrigation, and to provide adequate storage space for impounding occasional floods. Even with these costly structures, perfect regulation of the water-supply is difficult owing to the uncertainty of stream-flow. Consequently, any reliable forecast of stream-flow would greatly facilitate water-management. With this in mind, the Southwestern Forest and Range Experiment Station has developed a method of forecasting the spring-flow, March through May, for direct application to the Salt River in central Arizona.

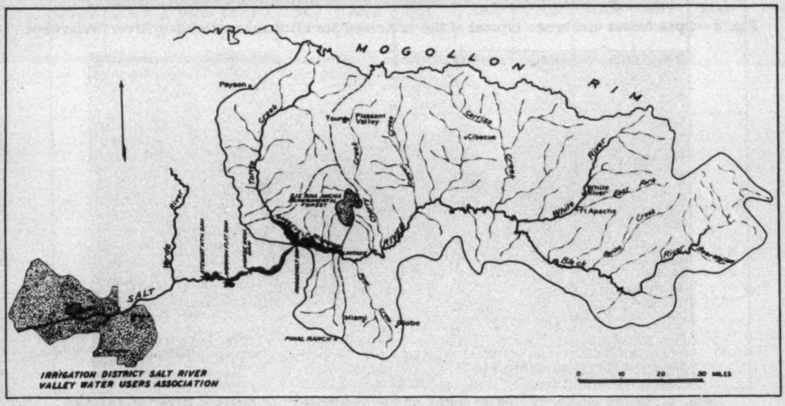
MOGOLLON RIM
Payson
Tonto Creek
Young
Pleasant Valley
Creek
Carrizo
Cibecue
Creek
White River
White River
East Fork
Ft. Apache
Creek
Black River
River
Verde River
SALT
RIVER
Globe
Miami
PINAL RANCH
IRRIGATION DISTRICT SALT RIVER VALLEY WATER USERS ASSOCIATION
0 10 20 30 MILES

Fig. 1--Salt River, Tonto Creek, and minor drainage-areas above Roosevelt Reservoir

Fig. 2--Semidesert vegetation found at the lower altitudes on the Salt River Watershed

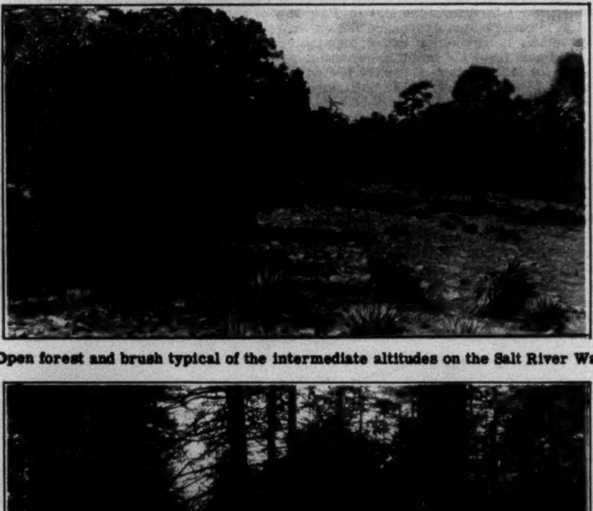

Fig. 3--Open forest and brush typical of the intermediate altitudes on the Salt River Watershed

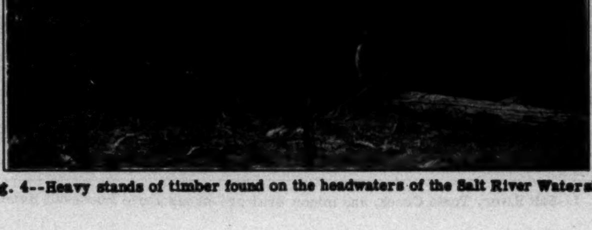

Fig. 4--Heavy stands of timber found on the headwaters of the Salt River Watershed

Approximately one-half of the population of Arizona is directly or indirectly dependent on the Salt River for irrigation, power, and related developments. Wartime production of foodstuffs and power, as well as proposed postwar developments, have increased the importance of water and emphasized the need for information contributing to water-management. Present development of irrigation and power in the Salt River Valley has been made possible through five storage reservoirs, of which four are on the Salt River above its junction with the Verde River, as shown on Figure 1. The largest, Roosevelt Reservoir, is farthest upstream and holds nearly three-fourths of the storage capacity of the whole system. Originally the capacity of the system was about eight acre-feet of water for every acre under cultivation, or water sufficient when full to supply irrigation-needs of the project for about two years. Unfortunately, the capacity has been decreased by sedimentation. The three lower reservoirs on the Salt River are primarily for synchronizing irrigation- and power-demands on the same water.

Characteristics of the Salt River Watershed

The Salt River Watershed above Roosevelt Reservoir is a rugged mountain mass of 4,310 square miles, with altitudes ranging from about 2,500 feet msl in the vicinity of the reservoir to 12,000 feet on the headwaters. The lower altitudes have a semidesert vegetation of shrubs and grasses (Fig. 2), cool to hot weather, and an average annual precipitation of 15 to 18 inches--high compared to most other southwestern drainages of similar altitude. The intermediate country has open timber and brush-cover (Fig. 3), temperate climate, and relatively high precipitation of 20 to 25 inches. The headwaters, covered with a heavy stand of pine, fir, and some spruce timber (Fig. 4), have a cool climate and precipitation ranging from about 22 to 35 inches annually.

By far the greatest portion of the flow of the Salt River occurs during the winter and early spring when the precipitation is most effective in producing stream-flow, as shown in Figure 5. COOPERRIDER and SYKES [see 1 of "References" at end of paper] have shown that while about 82 per cent of the annual stream-flow is produced during the winter period (October through May) only about 61 per cent of the annual precipitation occurs during that time.

The annual flow of the Salt River is highly variable with periods of low flow, usually of several years' duration, broken by one or more years with high flows. In 1905 the flow through what is now Roosevelt Reservoir averaged over 13 times that of the previous calendar year (4,496 compared to 331 second-feet), and in 1941 it was almost seven times the flow in the water-year 1940 (2,654 compared to 410 second-feet). The average flow for the five-year period 1910-14 was 30 per cent below the 42-year average flow of 1,180 second-feet, while during the 20 years, 1921-40, the flow was 25 per cent less than average. The accumulated deficiency during periods of low flow is compensated for by the very high flows occurring during infrequent flood-periods.

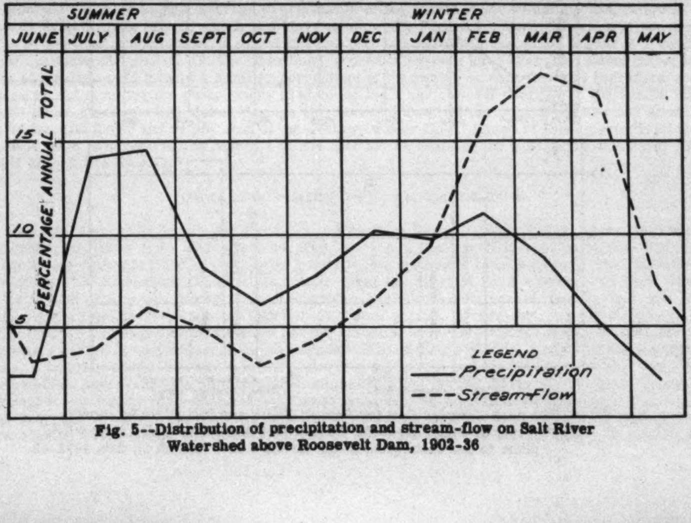

Fig. 5--Distribution of precipitation and stream-flow on Salt River Watershed above Roosevelt Dam, 1902-36

Relation of Salt River Watershed to Parker Creek in Sierra Ancha Experimental Forest

The Sierra Ancha Experimental Forest, a forest-research area devoted to the study of vegetation-stream-flow relationships, is located in the Salt River Drainage-Basin above Roosevelt Reservoir. In 1934 a stream-gaging station was constructed on Parker Creek, a small watershed within the experimental area. After records had been obtained for a few years, a close relationship in winter flow (October-May) was observed between Parker Creek and the Salt River at the head of Roosevelt Reservoir. This early observation has been confirmed by means of a correlation-analysis, utilizing the nine-year record from both streams. The computation revealed a good relationship expressed by the correlation-coefficient of 0.9927 with a standard error of estimate of ±59600 acre-feet, or an average deviation, estimated from actual, of about ten per cent. Although a close relationship exists between the total discharge of the two streams, the flow of the Salt River consistently lags behind the flow of Parker Creek, as shown on Figure 6A. On March 1 an average of 52 per cent of the winter flow of the Salt River has reached Roosevelt Reservoir (see Fig. 6B). This means that much of the potential flow of the Salt River is in transit, and, to a lesser extent, in storage in the form of ice and snow. The lag in the flow of the Salt River largely furnishes the basis for forecasting the flow of the Salt River from the flow of Parker Creek.

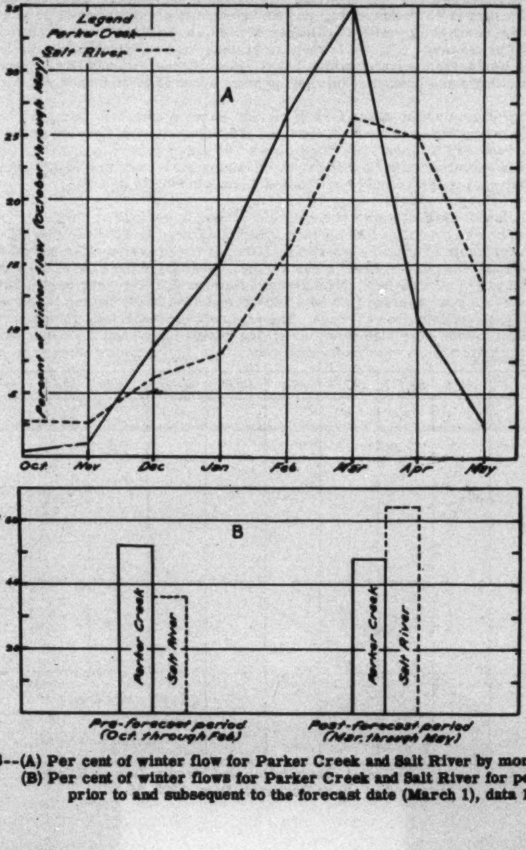

Fig. 6--(A) Per cent of winter flow for Parker Creek and Salt River by months
(B) Per cent of winter flows for Parker Creek and Salt River for periods prior to and subsequent to the forecast date (March 1), data 1935-42

As pointed out above, the forecast of stream-flow by this method is primarily based on the theory that the stream-flow during the prediction-period is the result of precipitation that has fallen prior to the date of the forecast and is in temporary storage on the watershed. However, another theory, which might be termed pattern-repetition, must also be considered. This theory suggests that during a winter of heavy precipitation there is usually a carry-over of heavy precipitation into the early spring, and, likewise, a dry winter is followed by a dry spring. The forecast may contain considerable error when the theory of pattern-repetition breaks down; for example, when a dry winter is followed by a very wet spring. It is, of course, the uncertainty of precipitation during the forecast period which throws an element of risk into all methods of stream-flow prediction.

The close relationship in stream-flow between the two streams as discussed above, is due to a number of reasons: (1) Parker Creek Drainage-Area is a miniature of the Salt River Basin as to relief, climate, soils, and vegetation; (2) winter storms occur more or less generally over both watersheds, resulting in similar gross precipitation on similar areas. The most evident reasons for the lag in the flow of the Salt River compared with that of Parker Creek are: (1) Size of area--millions as compared to hundreds of acres; (2) long compared to short stream-channels; and (3) short interval between occurrence of precipitation and return as stream-flow on Parker Creek. The precipitation on Parker Creek occurs largely as rain and rapidly melting snow, while on some small portions of the Salt River Watershed snow accumulates to melt in the spring.

However, the importance of accumulated snow on stream-flow of the Salt River is much less than on drainages in more humid and colder climates. On the basis of altitude and of available climatic data, less than 15 per cent of the watershed has temperatures that permit snow to accumulate throughout the winter. The average period during which snow falls but does not melt within a few days is short, usually not over three months. Furthermore, some of the snow that accumulates early in winter probably sublimates into the dry air before the spring thaw. Hence, the amount of stream-flow contributed through the melting of stored snow is not large and possibilities of forecasting stream-flow through such means as snow-surveys are limited.

Determination of date of forecast

With regard to the regulation of stream-flow, the earlier the forecast can be made the greater the economic value. However, a forecast early in the season would contain too great an error whereas one late in the season, although more accurate, would involve a relatively small percentage of the annual flow. Thus, for establishing the date of forecast, a balance must be found between accuracy and economic value.

February has the highest average precipitation of any month in the winter period, followed by a steady drop through March, April, and May, as shown by Figure 7. Since February is usually the month of greatest precipitation, it seems obvious that any forecast made prior to March 1 would contain considerable error. On the other hand, a predicting-date later than this, although perhaps more accurate, would involve a smaller percentage of the annual stream-flow and therefore would be less useful in aiding the water-users in planning their agricultural programs. Forecasts made for the three-month period, March through May, involve about 56 per cent of the average annual flow of the Salt River and 64 per cent of the average winter flow. Based on these considerations it seems most desirable to use March 1 as the date for forecasting the flow of the Salt River for the period March 1 to May 31.

Method of forecasting the flow of the Salt River

The total flow of Parker Creek from October through February was plotted against the total flow of the Salt River from March through May for each of the nine years of record (see Fig. 8). A regression-line was fitted to the plotted points by the method of least squares. The equation developed for this regression and which is used to make the forecast is: $E = (1488X + 98,726)$, where E = estimated or forecast flow of the Salt River for any March-May period in acre-feet, and X = actual flow of Parker Creek for any October-February period, in acre-feet. The correlation-coefficient for this regression is 0.9756 and the standard error of estimate is 68,008 acre-feet. Although a series of nine consecutive years does not constitute a random sample of all possible years, it is believed the data available are adequate since they include the flows of 1940 and 1941 which closely approach the minimum and maximum flows of the Salt River for the past 40 years. The regression can be revised and strengthened from year to year as new records become available. It should be pointed out that this regression would not continue to be applicable if anything occurs which would change the flow-conditions on one watershed and not the other. For example,

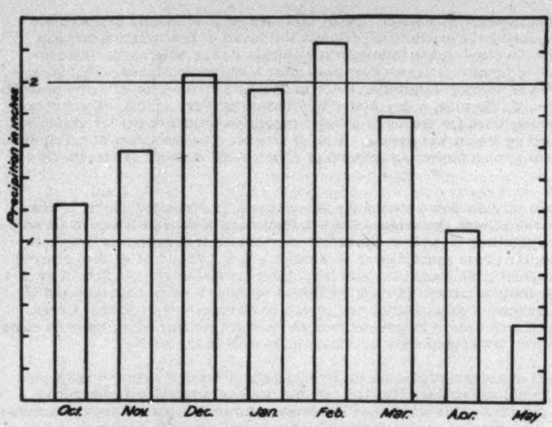

Fig. 7--Monthly precipitation over upper Salt River Watershed during winter period, 35-year average, 1902-36

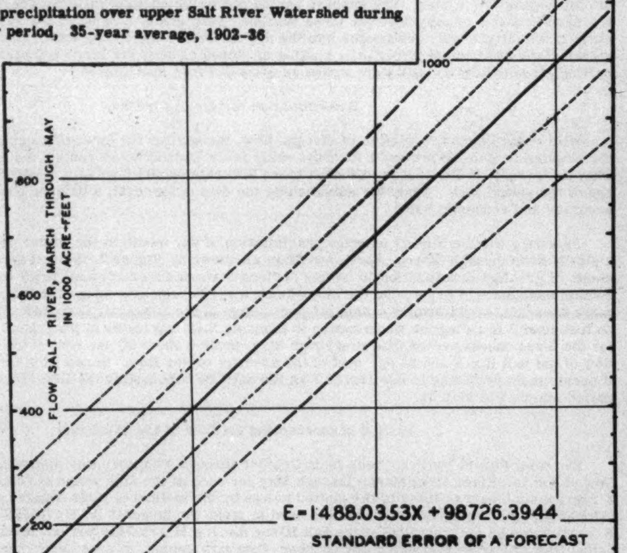

Fig. 8--Regression-line expressing relationship between flow of Parker Creek (October through February) and flow of Salt River (March through May) such a change might be brought about by opening the Parker Creek Watershed to grazing, a condition which might increase or decrease the stream-flow and thereby alter the existing relationship between the two streams expressed by the above regression.

To determine the accuracy with which the regression predicts the flow of the Salt River (March-May), the estimates for each year were calculated and tabulated beside the actual flow-volumes in Table 1. Included are the per cent deviations, estimated from actual, for each year. These indicate, as might be expected, that the deviations expressed as percentages are usually greatest during years of low flow.

Table 1--Deviation of forecast from actual flow of the Salt River, March through May

Year	Actual flow	Forecast flow	Difference	Deviation estimated from actual
	ac-ft	ac-ft	ac-ft	pct
1935	413,270	452,879	39,600	8.8
1936	382,500	314,492	-68,008	21.6
1937	492,600	570,434	77,834	13.6
1938	204,010	125,511	-78,499	62.5
1939	228,320	213,305	-15,015	7.0
1940	138,050	228,185	90,135	39.5
1941	1,108,100	1,059,997	-48,103	4.5
1942	272,870	314,492	41,622	13.2
1943	306,448	266,874	-39,574	14.8
Average	394,019	394,019	. . . . .	20.6

In addition to forecasting the flow of the Salt River, it is desirable to know the total error associated with each individual forecast. This may be expressed as the standard error of a single forecast and has direct application in determining the possible range of flow attached to each future prediction. For example, with odds of 19:1, or any other odds the water-users may wish to use, they can determine the possible minimum water-supply for any year. Likewise, with the same odds they can determine the possible maximum flow. Thus, a definite range of probable water-supply can be established each year to guide them in regulating water-use. The standard error of a single forecast may be determined by means of the following equation [2].

$$s_f = t\,s\sqrt{1/n + [(X - x)^2/Sx^2] + 1}$$

where $t = 1.040$ on seven degrees of freedom $(n - 2)$ for odds of 2:1, 2.365 on seven degrees of freedom $(n - 2)$ for odds of 19:1 [3], s = standard error of estimate (68,008 acre-feet), n = number of observations (nine years), X = flow of Parker Creek for any future October-February period, x = mean flow of Parker Creek for the October-February periods from 1935 to 1943, inclusive (198 acre-feet), Sx^2 = sum of squared deviations from the mean flow of Parker Creek (288,668). An example of the application of this concept is given later.

Application of method

The data for the year 1944 were selected to demonstrate the application of this method of forecasting. During 1944 the flow from Parker Creek (October-February) was 59 acre-feet. By substituting 59 for X in the regression-equation, the forecast for 1944 is

$$E = 1488 \times 59 + 98{,}726 = 186{,}520 \text{ acre-feet}$$

The standard error of forecast for 1944 is determined as follows: For odds of 2:1, substitute 59 for X and 1.040 for t in the following equation:

$$S_f = \pm (t)(68{,}008)\sqrt{1/9 + [(X - 198)^2/ 288{,}668] + 1} = 76{,}788 \text{ acre-feet}$$

For odds of 19:1 substitute 59 for X and 2.365 for t, giving $S_f = 174{,}607$ acre-feet. Hence, the estimated or forecast flow of the Salt River for the period March through May 1944 is 186,520 acre-feet, and the actual flow with odds of 2:1 should be within ± 174,607 acre-feet. Thus, for any given odds the range of error associated with each forecast may be calculated to indicate what the possible minimum and maximum flows might be. In the above example the water-users in 1944 would have known that they had two chances in three of getting more than 109,737 acre-feet of water (186,520 - 76,783); likewise, only one chance in three of exceeding 263,303 acre-feet (186,520 + 76,783). With odds of 19:1 they had 19 chances in 20 of getting more than 11,913 acre-feet (186,520 - 174,607), and only one chance in 20 of exceeding 361,127 acre-feet (186,520 + 174,607). Actually, the flow for the March-May period of 1944 was 190,770 acre-feet, within 2.2 per cent of the forecast flow.

Knowing what the possible minimum and maximum flows will be for any forecast should aid the Salt River Valley Water-Users' Association in planning their agriculture- and power-programs. With Roosevelt Reservoir fairly full in early spring, it is possible for high flows to overtop the spillways to the extent that downstream flood-damage might result. Advance information of the amount of water expected gives the operators opportunity to release excess water without damage. It also gives them a fair idea of how much need be released without loss of stored water beyond the safety point, and, during years of expected low flows, to provide for proper use of water during the current year as well as for the hold-over necessary for the following year.

Contribution of Tonto Creek to Roosevelt Reservoir

Up to this point only the flow of the main stem of the Salt River has been considered as contributing to the Roosevelt Reservoir. However, besides the Salt River, Tonto Creek, and several unimportant intermittent streams also flow into Roosevelt Reservoir. As the storage in the reservoir is managed as a unit, it is desirable to know the flow of this tributary area. The topography, climate, and ground-cover of Tonto Creek and Salt River drainage-basins are similar. During the period 1914 to 1940 the Salt River Valley Water Users' Association and the United States Geological Survey determined by rather rough measurements that the March-May flow of Tonto Creek is about 12 per-cent of that of the Salt River. In order to compute the estimated total inflow to Roosevelt Reservoir it would probably be sufficiently accurate to add 12 per cent to the estimated flow of the Salt River for the period March through May. No attempt has been made to evaluate the errors associated with it. If the records for Tonto Creek had been as accurate as those for Salt River, they could have been incorporated directly into the regression-equation, eliminating the necessity of adding 12 per cent to the flow of the Salt River to obtain the total inflow to Roosevelt Reservoir.

References

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[2] Obtained from Dr. GEORGE W. SNEDECOR, Director, Statistical Laboratory, Iowa State College, and Dr. H. G. WILM, in charge, Division of Forest Influences, Rocky Mountain Forest and Range Experiment Station. Theory of this concept is discussed in an article by C. EISENHART in the Annals of Mathematical Statistics, v. 10, p. 162, 1939.

[3] For other odds see table of t-values in Statistical Methods for Research Workers, by R. A. FISHER.

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AN ACCOUNTING OF THE DAILY ACCRETION, DEPLETION, AND STORAGE OF SOIL-WATER AS DETERMINED BY WEIGHING MONOLITH LYSIMETERS

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Abstract--Daily values of accretion, depletion, and storage of soil-water under grass-cover are presented for a two-year period from data obtained by weighing monolith lysimeters located at the United States Soil Conservation Service Research Station, Coshocton, Ohio. Data from two soil-types are given for a one-year period. Graphs of daily precipitation and condensation are presented as a measure of accretion, and graphs of daily evapotranspiration, percolation, and runoff present data of the depletion-processes. A graph shows the daily soil-moisture content of the 0- to 40-inch profile which constitutes a measure of changes in storage of soil-moisture. The latter values expressed in inches of water in the profile were obtained from a curve based on the accretion and depletion of soil-water as determined by the weighing lysimeters and further substantiated by occasional soil-moisture determinations made in the field.

Summaries of all the accretion- and depletion-factors by months appear in tabular form. In 1943 the annual accretion amounted to 38.64 inches of which 34.50 inches were due to precipitation and 4.14 inches to condensation. The annual depletion amounted to 41.36 inches, of which 33.28 inches, 7.97 inches, and 0.11 inches were due to evapotranspiration, percolation, and runoff, respectively.

The weighing monolith lysimeters at the Coshocton (Ohio) Soil Conservation Research Station afford a unique opportunity for a rather complete study of the disposal of precipitation. Although the definition of "lysimeter" [see 4 of "References" at end of paper] places the major emphasis on the study of natural precipitation percolating through soil, this is but one phase of the hydrologic cycle and, under some circumstances, this phase is quantitatively one of the least important. In addition to percolation, it is the purpose of this paper to show in detail the magnitude of moisture-accretion, other moisture-depletion, and storage of moisture in a soil-profile under grass-cover, for a period of two years.

It is significant to note that although lysimeters have been used as early as the Seventeenth Century, the first soil-block or monolith lysimeters with self-recording weighing mechanism were built by the Soil Conservation Service at Coshocton in 1937. Numerous publications pertaining to lysimeters have presented data on percolation. Many of these lysimeters were of the filled-in type; some had no provision for runoff and others had relatively shallow depths of about three feet or less. Although measurements of evapotranspiration have been made in the past under relatively artificial climatic conditions and soil-conditions, it is believed the equipment at Coshocton, described below, provides data that more nearly approach true values of daily accretion and depletion of soil-water than any heretofore available.

Experimental procedure

Description of lysimeters--All lysimeters used in this study are 1/500 acre in surface area (length 14 feet, width 6.22 feet) and are eight feet deep. These blocks of earth were isolated on the sides by vertical concrete walls and on the bottom by perforated steel plates parallel to the surface of the ground. The concrete walls were constructed on the surface and lowered around the soil-blocks by excavating beneath the cutting edge of the concrete walls. When the bottom of the walls reached the eight-foot depth, the bottom steel plates were jacked into place completing the isolation of the soil-block. A very important feature of the design was the elimination of the artificial vertical seepage-plane between the soil-block and the concrete walls by inserting, at different depths, four three-inch steel strips or "piston rings" which extend half into the concrete walls and half into the soil-block.

Provision is made on all lysimeters to collect and measure the surface runoff and the percolation from the eight-foot depth. There are three lysimeter boxes at location Y102 and four lysimeter boxes at Y103. One at each location is placed on scales which record the weight at ten-minute intervals. Although the total weight of the soil-block and concrete totals about 60 tons, these scales are capable of measuring changes in weight of five pounds which is equivalent to 0.01 inch of water over the area.

The design and construction of these lysimeters have been described in detail by GARSTKA [3], RIESBOL and SHERMAN [7], and KOHNKE, DREIBELBIS and DAVIDSON [4]. Although records from this equipment date back to 1938, a number of operational difficulties had to be overcome before some of the measurements could be relied upon. The records included in this paper are believed to be free from errors.

The lysimeter-studies of KOHNKE, DREIBELBIS, and DAVIDSON [4], LEBEDEFF [6], and others showed that an unnatural condition existed at the bottom of their lysimeters where the soil-profile and the substrata were separated. Water accumulated at this separation-layer as the tension from water-surfaces below was removed. The surface-tension of the water at this section also reduced percolation. Where artificial tension was applied to this layer, percolation was greater. Although the authors recognize this shortcoming of lysimeters in general, it is emphasized that the lysimeters at Coshocton are comprised of undisturbed soil-profiles extending two to three feet into bedrock (shale and sandstone) which is naturally shattered to such an extent that the tension from below is normally broken. It may be concluded that the relationships of soil-moisture and values of percolation obtained from the Coshocton monolith lysimeters more nearly approach natural conditions than those data from filled-in and soil-block lysimeters in which the entire depth is made up of soil.

It cannot be definitely concluded that there is, or is not, an error in values of percolation for the Coshocton monolith lysimeters due to the absence of tension (negative pressure) at the bottom of the lysimeters. If there is, it is believed that it is small.

Description of soil-types--The soil on lysimeter Y102 is classified as the Muskingum silt-loam and on Y103 as the Keene silt-loam, both soils being of residual origin (shale and sandstone) and belonging to the Gray Brown Podzolic group. The two soils differ distinctly in the hydrologic characteristics of their profiles. The subsoil of the Muskingum silt-loam is a rather pervious loam or silt-loam and is well drained. The subsoil of the Keene silt-loam is a heavy silt-loam to silty clay-loam and grades into a heavy, relatively impervious silty clay at the 24-inch depth, which provides only fair drainage. Both soils are rather shallow. The soil extends to a depth of three to four feet; disintegrated rock extends another two to three feet; and the lowest two to four feet contain undecomposed parent rock. Data on the mechanical analysis and other physical properties of these soils, as well as a more detailed description of their profiles, were previously given [1].

Methods of obtaining experimental data--All of the data on moisture-accretion, depletion, and storage were obtained from the weighing lysimeters described above. Percolation and surface-runoff were determined directly by measurement in separate collector-tanks equipped with automatic recorders. Evapotranspiration (ET) and condensation and absorption (CA) were determined from the hourly weight-records automatically recorded every ten minutes. On rainless days during which the hourly weight-increment increased, the amount of increase was attributed to condensation and absorption. When the weight decreased, the amount of decrease was attributed to evapotranspiration. In both cases allowance was made for any loss in weight due to percolation for the periods. ET includes, therefore, also the water of interception by the plants which was largely if not entirely removed by evaporation. Although precipitation was also measured directly by rain-gages on the adjoining area, the precipitation-data used in this paper were obtained from lysimeter weight-records and the increase in weight during periods of rain (defined by recording rain-gage record) was attributed to precipitation after allowing for losses in weight due to percolation or runoff. All of these data were obtained for 24-hour periods ending at midnight.

Moisture-storage changes determined from the lysimeter weight-records apply to the eight-foot profile. These moisture-data for the entire eight-foot profile were believed to be less a factor in water-plant relationships and rainfall-runoff studies than similar data for the top 40 inches of soil. As studies were being made of fluctuations of moisture in the 0- to 40-inch profile in adjacent watersheds and as only periodic observations can be obtained, it was necessary to use the lysimeter-records for a guide in the interpolation of soil-moisture fluctuations between sampling dates. A soil-moisture curve for the 0- to 40-inch depth of soil showing probable daily changes throughout the year was worked out based on a number of assumptions separating the 0- to 40-inch depth from the remainder of the eight-foot profile. These rules and assumptions were derived by studying the lysimeter weight-records in connection with the moisture-data obtained from periodic sampling of the 40-inch profile in the adjacent watersheds. Although it was not feasible to follow an inflexible rule in working out such a curve, the general considerations involved were all closely related to the data on accretion and depletion. All ET was assumed to come from the 0- to 40-inch depth of soil, regardless of season. All percolation was assumed to come from below the 40-inch depth when the daily percolation did not exceed 0.2 inch. When greater than this value, one-third of the percolation was assumed to come from the 0- to 40-inch zone. In winter when the soil was frozen all precipitation which did not run off was assumed to be contained within the 0- to 40-inch depth. The rest of the year when precipitation did not exceed 0.25 inch that part not running off was attributed to moisture-accretion in the 0- to 40-inch depth. When exceeding this amount the allocation of the precipitation retained on the plot was somewhat dependent on season, soil-moisture content, and frequency of rainfall. In spring when the soil was nearly saturated, only one-fifth of the non-runoff precipitation exceeding 0.25 inch, plus 0.25 inch was attributed to the 0- to 40-inch depth and the remainder assumed to contribute to the lower zone. In the summer, when transpiration was high and when the soils were much dryer, a greater portion, and often all of the precipitation, was considered as being held in this top zone. Exceptions to the above rules were made when the data indicated that such was the logical procedure. While the soil-moisture curve worked out is not absolutely accurate, it is believed to be within 0.5 inch most of the time and often closer than 0.2 inch. At times the values on the calculated graph of soil-moisture appeared to be more reliable than the sampled points.

Discussion of results

Accretion--Of the two accretion-factors, precipitation and CA, the former is the more important. The annual precipitation for 1943 and 1944 (Table 1) varied from 34 to 38 inches which was 85 to 89 per cent of the total water added to the lysimeters. Almost all of this precipitation except that for the period December 10-31, 1944, fell in the form of rain. The graphs of daily precipitation on Figures 1, 2, and 3 give a picture of the distribution of the rainfall throughout the year. September, 1943, was the month of lowest rainfall. Precipitation, its amount and distribution, played the most important part in causing runoff, percolation, and changes in soil-moisture. It plays a lesser part in affecting evapotranspiration.

The daily values of precipitation which were obtained from the weighing lysimeters, and are therefore a measure of the moisture falling on the ground-surface, were consistently higher than those obtained by the Fergusson recording rain-gage. The annual values recorded by the gage range from 2.5 to seven inches lower than those obtained on the weighing lysimeters. These differences are similar to those obtained by RIESBOL [8] in comparing a pit-gage with the standard rain-gage. The data of RIESBOL as well as the data in this paper, indicate rain-gage catches by the standard rain-gage are probably lower than the true value.

Condensation and absorption of moisture (CA) on the surface of the lysimeter is the lesser of the two accretion-factors--totaling four to six inches annually. The monthly values (Table 1) as well as the daily values (Table 2 and Figs. 1, 2, and 3) show that the amount of this type of accretion is small in May, June, July, and August, and is greater in the remainder of the year. Records show that this accretion takes place when the temperature at the ground-surface is lower than the dew-point temperature for the air. This most frequently occurs during the late afternoon, night, and very early morning. The total CA for 1944 was about the same on both Y102 and Y103.

LEBEDEFF [6] studied the phenomenon of condensation in soils in Odessa. He found many instances during the night in which the specific humidity of the atmosphere is greater than the vapor-pressure in the upper layer of the soil. Under such conditions the atmospheric vapor must enter the soil under the influence of the difference in vapor-pressure and condense in the soil. In three nine-month periods (March-November) he reported condensation on 126, 162, and 179 days, respectively. From his data, which apparently do not include dew, he calculated the annual accretion due to condensation to be 72 mm (2.83 inches) which was 16 to 18 per cent of the annual precipitation (400 to 450 mm). In Arlington, Virginia, THORNTHWAITE and HOLZMAN [9] found the condensation for a ten-month period in 1939 to be 1.81 inches. Their monthly values did not show the range of seasonal fluctuations as did those at Coshocton. Their values for summer were greater and their values for the remainder of the year were smaller than those shown in this paper.

The daily values of CA shown on Figures 2 and 3 for the period after December 10, 1944, the average daily CA for December 1944 (Table 2), and the monthly totals for December 1944 (Table 1), are affected to a great extent by drifting snow. There were, however, some periods when there was little or no wind-movement and when the snow-surface was crusted during which it could be concluded that the lysimeter weight-records were reliable. For these periods the daily values of CA amounted to from 0.10 to 0.18 inch per day, which values are greater than when no snow is on the ground. This apparently corresponds to general observations in the Great Lake Region where the moisture-content of snow has been known to increase during periods of no precipitation. Fortunately, the only part of the two-year period during which the records were complicated by snow was that subsequent to December 10, 1944.

Table 1--A monthly summary of the accretion, depletion, and storage of soil-water as determined by weighing monolith lysimeters

Month	Accretion			Depletion				Storage 8-foot profile	
	Precipitation	Condensation (CA)	Total	Evapotranspiration(ET)	Percolation	Runoff	Total	Mon.net increase	Mon. net decrease
	in	in	in	in	in	in	in	in	in
1943				Lysimeter Y103, 1943					
January	2.40	0.72	3.12	1.56	1.18	0.00	2.74	0.38	...
February	1.94	0.42	2.36	1.91	1.21	0.00	3.12	...	0.76
March	4.70	0.46	5.16	3.26	2.32	0.01	5.59	...	0.43
April	3.17	0.25	3.42	2.50	0.66	0.01	3.17	0.25	...
May	7.05	0.09	7.14	4.06	1.91	0.04	6.01	1.13	...
June	2.50	0.12	2.62	4.87	0.53	0.02	5.42	...	2.80
July	4.05	0.10	4.15	4.63	0.05	0.02	4.70	...	0.55
August	3.61	0.12	3.73	5.10	0.06	0.01	5.17	...	1.44
September	0.51	0.38	0.89	2.37	0.02	0.00	2.39	...	1.50
October	1.81	0.43	2.24	1.09	0.02	0.00	1.11	1.13	...
November	1.69	0.40	2.09	0.99	0.01	0.00	1.00	1.09	...
December	1.07	0.65	1.72	0.94	0.00	0.00	0.94	0.78	...
Total, yr.	34.50	4.14	38.64	33.28	7.97	0.11	41.36	4.76	7.48
Pct total accre.	89.3	10.7	100	...	...	...	...	...	...
Pct total deple'n	...	...	...	80.4	19.3	0.3	100	...	...
1944				Lysimeter Y103, 1944					
January	1.15	0.73	1.88	1.14	0.04	0.00	1.18	0.70	...
February	2.14	0.88	3.02	1.88	0.25	0.00	2.13	0.89	...
March	6.10	0.62	6.72	3.28	2.92	0.00	6.20	0.52	...
April	3.83	0.49	4.32	3.05	1.67	0.00	4.72	...	0.40
May	2.40	0.17	2.57	3.97	0.07	0.00	4.04	...	1.47
June	3.15	0.17	3.32	5.35	0.04	0.01	5.40	...	2.08
July	2.46	0.07	2.53	4.68	0.02	0.01	4.71	...	2.18
August	4.39	0.07	4.46	4.27	0.02	0.02	4.31	0.15	...
September	1.84	0.20	2.04	2.89	0.01	0.01	2.91	...	0.87
October	1.81	0.45	2.26	1.70	0.01	0.00	1.71	0.55	...
November	1.25	0.39	1.64	1.01	0.00	0.00	1.01	0.63	...
December	4.54	1.56[a]	6.10	2.95[a]	0.00	0.01	2.96	3.14	...
Total, yr.	35.06	5.80	40.86	36.17	5.05	0.06	41.28	6.58	7.00
Pct total accre.	85.81	14.19	100	...	...	...	...	...	...
Pct total deple'n	...	...	...	87.62	12.23	0.15	100	...	...
1944				Lysimeter Y102, 1944					
January	1.13	1.10	2.23	1.52	0.00	0.00	1.52	0.71	...
February	1.97	0.66	2.63	1.28	0.01	0.02	1.31	1.32	...
March	6.98	0.39	7.37	2.01	3.46	0.02	5.49	1.88	...
April	4.30	0.32	4.62	2.28	3.22	0.01	5.51	...	0.89
May	2.49	0.11	2.60	4.53	0.50	0.00	5.03	...	2.43
June	3.80	0.12	3.92	4.52	0.10	0.05	4.67	...	0.75
July	2.72	0.20	2.92	4.25	0.02	0.06	4.33	...	1.41
August	4.72	0.19	4.91	4.38	0.00	0.16	4.54	0.37	...
September	2.07	0.43	2.50	3.16	0.00	0.04	3.20	...	0.70
October	1.90	0.76	2.66	2.26	0.00	0.01	2.27	0.39	...
November	1.48	0.81	2.29	1.69	0.00	0.00	1.69	0.60	...
December	4.55	1.44[a]	5.99	2.61[a]	0.02	0.06	2.69	3.30	...
Total, yr.	38.11	6.53	44.64	34.49	7.33	0.43	42.25	8.57	6.18
Pct.total accre.	85.37	14.63	100	...	...	...	...	...	...
Pct total deple'n	...	...	...	81.63	17.35	1.02	100	...	...

[a] Exaggerated values due largely to drifting of snow.

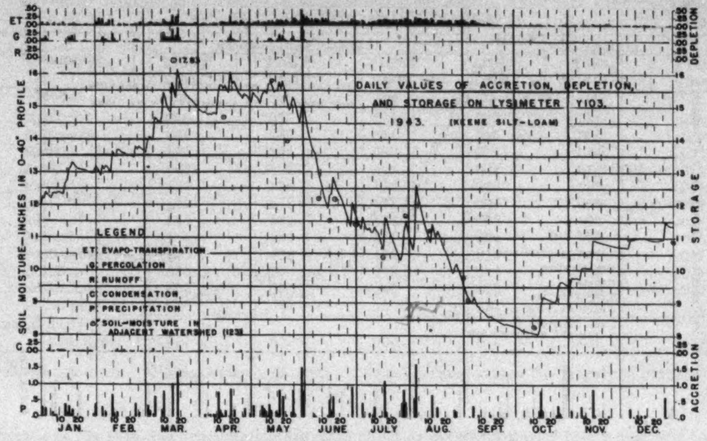

Fig. 1--Daily values of accretion to, depletion from, and storage of soil-water in lysimeter Y103 (Keene silt-loam, in meadow), 1943

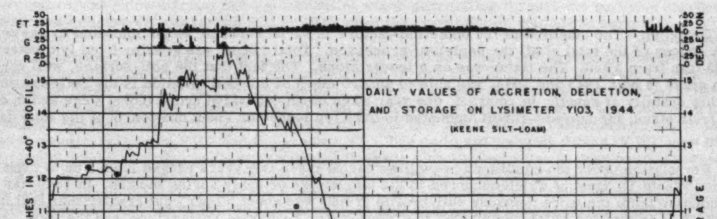

Fig. 2--Daily values of accretion to, depletion from, and storage of soil-water in lysimeter Y103 (Keene silt-loam, in meadow), 1944

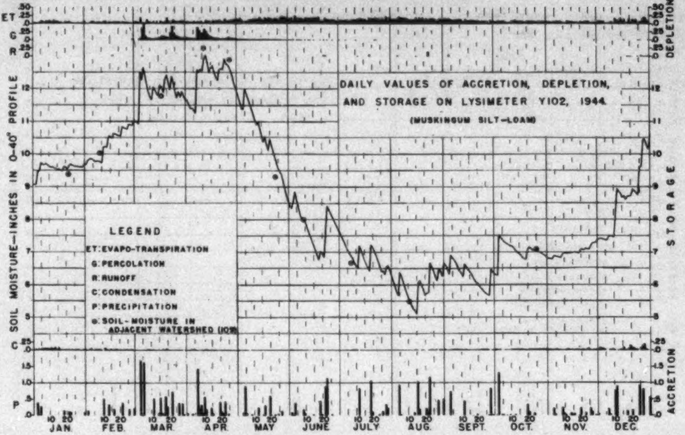

Fig. 3--Daily values of accretion to, depletion from, and storage of soil-water in lysimeter Y103 (Muskingum silt-loam, in meadow), 1944

Depletion--The smallest of the depletion-factors is surface-runoff which amounted to one per cent or less of the total of all the depletion-processes. Total runoff was greater from lysimeter Y102 than from Y103. The latter was on a lesser slope. The fact that the soil-surface, well covered with grass in both 1943 and 1944, was able to absorb much of the precipitation is the main reason for the low quantity of runoff. In contrast, one year when clean cultivated crops (corn) were grown on the lysimeters, the surface-runoff amounted to over ten inches or about one-fourth of the total depletion.

Percolation under the conditions prevailing during these two years ranged from five to eight inches (Table 1), most of which occurred in the late winter or early spring months. In 1944, the percolation from the more pervious soil-profile (Y102) was about 50 per cent greater than that from Y103. It is this water which contributes to ground-water recharge, spring-flow, and the like. Records for other years show that when more of the accretion is depleted in the form of surface-runoff, as described above for the year in corn, there is correspondingly less water available for percolation.

It has been suggested that the percolation-data are unnatural and excessive since provision is made for free drainage. KOHNKE, DREIBELBIS, and DAVIDSON [4], in their review of literature on lysimeters, have concluded that the provision of free under-drainage for percolation-water may decrease rather than increase the amount of percolation. This is based on the fact that the downward flow of water in a continuous profile is enhanced by the presence of a large area of wet surfaces but when this area is reduced or cut, the surface-tension of the water slows up the drainage-process.

Percolation normally occurs mostly in the winter and spring. During summer and fall when the soil-moisture content is generally much lower only small quantities of water, if any, usually percolate through the soil. In relatively dry periods, such as that in 1944, the percolation (June-November) amounted to about 0.10 inch--a negligible amount. The response of percolation to precipitation is evident during the wet months of the year. When appreciable amounts of precipitation fall at a time when the soil-moisture storage is high and the soil-surface is protected, quantities of infiltration are large, as, for example, in March, 1943, at which time daily values of percolation noticeably increased. In dry periods, such as the latter part of March and early April of 1945, percolation was

Table 2--Average daily evapotranspiration and condensation, lysimeters Y102 and Y103, by months, 1943 and 1944 (meadow)

Lysimeter	Evapotranspiration			Condensation		
	Y103,[a] 1943	Y103,[a] 1944	Y102,[b] 1944	Y103,[a] 1943	Y103,[a] 1944	Y102,[b] 1944
Month	in	in	in	in	in	in
January	.050	.037	.049	.023	.024	.035
February	.068	.065	.044	.015	.030	.023
March	.105	.104	.065	.015	.020	.013
April	.083	.102	.076	.008	.016	.011
May	.131	.128	.146	.003	.005	.004
June	.162	.178	.151	.004	.006	.004
July	.149	.151	.137	.003	.002	.006
August	.165	.138	.141	.004	.002	.006
September	.079	.096	.105	.013	.007	.014
October	.035	.055	.073	.014	.015	.025
November	.033	.034	.056	.013	.013	.027
December	.030	.095[c]	.084[c]	.021	.050[c]	.046[c]
Annual daily average	.091	.099	.094	.011	.016	.018

[a] Keene silt-loam. [b] Muskingum silt-loam. [c] Exaggerated values due largely to drifting of snow.

much less. In 1943, the precipitation had little effect on percolation after June 2, and only very small quantities of water percolated through the soil after that date. In 1944, most of the water lost through percolation occurred during the months of March and April on both lysimeters, although an appreciable amount was also lost during May on Y102. It is emphasized that the precipitation for both years was below normal and the amount of water percolating through the soil was appreciably lower than during wet years like that of 1940 when the precipitation was above normal.

Evapotranspiration (ET) ranging annually from 33 to 36 inches, is the largest and most important of the depleting processes and comprises 80 to 87 per cent of the total annual depletion. It should be noted (Table 1) that in 1944 the total ET for lysimeter Y103 exceeded the total precipitation. In no case was the total ET greater than the combined precipitation and CA. Although the total ET for lysimeter Y103 in 1944 was greater than that for Y102, the difference is small. For some months lysimeter Y102 had the greater ET. The daily and monthly values of ET show the natural fluctuation of this process throughout the year with highest rates in the growing season May-August. The total losses by ET for the four-month periods, May-August, have averaged 18.09 inches or an average of over 4.5 inches per month. It is likely that about two-thirds of this loss is due to transpiration alone. MILLER [5] estimated from data obtained in Kansas that an acre of corn would transpire approximately 11 acre-inches of water during the growing season. These values emphasize the importance of soil-moisture storage both for crop-production and for runoff-control. Although the growing season extends beyond August, the ET-rates decrease due both to lower transpiration as well as lower evaporation-rates, which in turn are influenced largely by weather, season, and soil-moisture content.

The difficulty of obtaining accurate values of evapotranspiration under natural conditions has been realized for a long time and was well emphasized by THORNTHWAITE and HOLZMAN [9]. In addition to reviewing the literature on this subject of evaporation from surfaces of land and water, they gave daily values of rainfall, condensation, and evapotranspiration for most of the year 1939. The evaporation- and condensation-data were obtained from an equation which gives the rate of moisture-transfer in terms of measurement of wind-velocity and moisture-concentration at two levels directly above the ground-surface. Although their months of greatest ET were likewise confined to the period May to August, the magnitude of their values was only about one-half those ET-values shown on Tables 1 and 2 for the Coshocton lysimeters. Subsequent to publication, the authors recomputed some of the values of evapotranspiration based on a revision of their equation. For the ten months in 1939, the revised value of evapotranspiration was 20.71 inches instead of the former value of 11.79. Net depletion-values which were given as an indication of evapotranspiration by DREIBELBIS and POST [2] amounted to 33.64 and 33.81 inches for the wheat-crop on the Muskingum silt-loam and Keene silt-loam, respectively, for the 12-month period ending August, 1940. These values were obtained from an equation based on accretion, depletion, and storage of soil-moisture.

Records show that ET takes place most rapidly during that part of the day when the air-temperature is rising. In the mid afternoon the ET-rate usually decreases rapidly. Most of the ET-values shown on the graphs and in the tables for the period after December 10, 1944, are exaggerated due to drifting of snow off the lysimeters. During some periods when it was definitely known that drifting was not taking place the weight-loss figures show the ET-values to be very high--as much as 0.22 inch in one day. Air-temperatures remained below 32°F during those days. The loss of snow in periods of subfreezing temperature is not uncommon as, at times, an entire snow-cover disappears from fields on cold clear days. Although THORNTHWAITE and HOLZMAN [9] found that a blanket of snow was responsible for the suppression of evaporation under the condition of their observations, they point out that evaporation from a snow-field may be large when suitable atmospheric conditions prevail.

Storage of soil-moisture--It is often desirable for agriculturists, hydrologists, and others to know the amount of soil-moisture contained in a unit-depth of soil for any given day of the year. This value is not only useful in agriculture in studies of soil-water-plant relationships but also in flood- and erosion-control and water-conservation studies when used in connection with other hydrologic data. As no accepted procedure for obtaining automatically a continuous record of soil-moisture is available, an attempt was made to work out a probable soil-moisture curve showing the inches of water contained in the 0- to 40-inch depth of soil for every day of the year. This method is described under the section on experimental procedure above. Such curves (see Figs. 1 and 2) were derived for the Keene silt-loam for 1943 and 1944, and for the Muskingum silt-loam (see Fig. 3) for 1944. These curves serve as a reasonably close indication of the quantity of soil-water stored for any day of the year. They also serve to contrast soil-moisture differences by soil-type as well as by different years. The latter contrast is due largely to the change in meteorological conditions from the year 1943 to 1944, while vegetative conditions (meadow) remained nearly the same. The heavier soil (Keene silt-loam) retained at all times more moisture in the profile than the lighter soil (Muskingum silt-loam). During the period January to April to a fair degree, and from September to December to a large degree, the daily increases and decreases in soil-moisture vary little by soil-type. During the June-July period of the growing season, however, the daily depletion of soil-moisture from storage is greater from the heavier soil probably because of the greater amount of water stored there.

In comparing the data from the Keene silt-loam for both years, 1943 and 1944, the influence of precipitation on moisture-storage is evident from January to April and from October to December, during which periods the amount of moisture stored gradually increased until the peak was reached. These peaks occurred in March, 1943, and in April, 1944. The storage in 1943 reached its minimum near the middle of October, while in 1944 the minimum was reached on August 15, although the storage nearly reached the minimum value again on September 27.

It is interesting to note that in both 40-inch profiles of the well-drained soil (Muskingum) and the less well-drained soil (Keene), there was a relatively small amount of moisture stored during the June-September period. The calculated maximum (saturation) capacity of this depth of soil to store was 16.8 inches of water in the former soil and 17.1 inches in the latter. It can be seen, therefore, that during the season of intense rainfall (June-August) there was sufficient empty storage-space in the 40-inch profile to take up as much as eight inches of water before reaching saturation. As the ground-cover was grass, practically all of the rainfall was absorbed by the soil, there being almost no surface-runoff. Contrarily when corn was grown on the lysimeters, not all of the rainfall could be absorbed by the unprotected soil and there was much runoff and considerable loss of soil. Consequently, one of the major problems in soil- and water-conservation is to grow the necessary crops, yet control the water-intake of the soil so as to utilize the large water-storing capacity of the soil and thus reduce the quantity of the damaging surface-runoff.

The rate of reduction of soil-moisture storage in 1944 for the two soil-types (Figs. 2 and 3) for periods between rain-storms appears to be such that depletion-curves could be derived. However, the soil-moisture curves for the Keene soil for 1943 (Fig. 1) differ materially from the corresponding curves in 1944 (Fig. 2) in the range of moisture-content below about nine inches. The depletion-curve for September 17 to October 12, 1943, shows a lower rate of drop than those portions of the curves for 1944 at corresponding moisture-contents which occurred in July. The ET-rates were much greater in the middle of the growing season (July, 1944) than at the end of the season (September-October, 1943) which probably accounts for the difference. The ET-rates near the end of September were greater in 1944 than at the same period in 1943. Air-temperature averaged nearly 15° higher in 1944 for this period. The fact that the weather (temperature, relative humidity, and wind-movement) is seldom the same in different years, probably eliminates the possibilities of establishing normal recession-curves for soil-moisture.

The rapid increases in the moisture-curves in December, 1944 (Figs. 2 and 3), are not truly soil-moisture increases. At this time there were definite increases in weight of the lysimeter-boxes, but most of this increase was due to the accumulation of snow on the surface.

In most cases the soil-moisture determined on the adjacent watershed by the field-sampling corresponds closely to the values represented by the curve. A notable exception occurred in spring when the soil was saturated or nearly so. Under these conditions perched water-tables were found on the Keene silt-loam which resulted in a greater contrast between the lysimeter- and watershed-soils. This contrast may be due, possibly, to exaggerated values obtained by field-sampling in which the soil may receive an additional wetting as the soil-auger is pulled through the perched water-table. It is also possible that the soil-moisture conditions in lysimeters do not exactly simulate those of the adjacent watershed under conditions of saturation. The field soil-moisture values for the Keene silt-loam in 1944 (May-October) do not correspond as closely to the curve as the others. It is likely this is due, in part at least, to the fact that the vegetative (meadow) conditions on the lysimeter were not exactly representative of the adjacent watershed. A greater density of vegetation on the watershed possibly resulted in a more rapid depletion of its soil-moisture than the lysimeter weight-records would indicate.

Although the soil-moisture curves are not absolutely accurate, they do serve as a reasonably accurate approximation of the soil-moisture stored for any day of the year. This is especially valuable for periods just preceding storms when it is difficult and often impossible to determine the moisture stored in the soil at that time unless actual field-observations happened to be made at that particular time.

Summary

The accretion of water to the ground-surface in the form of precipitation and condensation-absorption (CA) and the disposal of this water in the form of surface-runoff, evapotranspiration (ET), percolation, and changes in storage of soil-moisture as quantitatively determined by weighing lysimeters are presented in tables and graphs for two years.

Precipitation, the major accretion-factor, as measured on the ground-surface by the weighing lysimeters is greater than that measured in the recording rain-gage.

The quantity of water added to the lysimeters by the condensation mostly in the form of dew is significant. This quantity is seldom, if ever, measured in rain-gages. The largest amounts of CA occurred in the period from September to May.

Amounts of runoff for both years are small due to the good vegetal cover on the soil-surface.

These lysimeters furnish reliable data on quantities of percolation at an eight-foot depth for the types of soil-profiles represented. Although the rainfall for both 1943 and 1944 was below normal, there was considerable percolation. This can be attributed to the presence of a grass-cover protecting the soil-surface from the beating and puddling action of rain-drops, thus keeping the soil open to take up rainfall at rather high rates thereby reducing the quantity of surface-runoff. On a less protected soil-surface, as corn-land, much more water runs off the surface and the percolation is less. The United States Soil Conservation Service research and field programs are greatly needed to supply more reliable data for this condition.

Evapotranspiration (ET) accounts for the greatest use of water supplied to the soil. For the most part these data are actual measurements under conditions, very close to, if not absolutely, natural. It was found that the values obtained under these conditions are almost double those obtained by THORNTHWAITE and HOLZMAN [9] in Virginia in 1939 (later studies by THORNTHWAITE show that their values of evapotranspiration should be increased almost 70 per cent). The monthly distribution of ET throughout the year is about the same in both cases. Naturally the greatest disposal of water by this process occurs during the growing season, May-August, when about 18 inches is used up.

The measurement of ET and condensation by weighing monolith lysimeters as described in this paper seemingly will hasten the analysis and solution of many hydrologic problems which have been delayed because of the lack of the necessary data. While the data submitted herein apply only to grass-cover, studies are in progress covering the various crops in the rotation.

The data on changes in storage of moisture in the soil-profile, which are so useful in agricultural, hydrologic, and hydraulic problems, show high quantities of water stored with correspondingly little unfilled storage-space in winter and early spring, and low quantities of water stored with correspondingly large quantities of unfilled storage space in late spring, summer, and fall. In the latter period there is usually space in the 40-inch soil profile to take up eight inches of water before reaching saturation.

These weighing monolith lysimeters afford opportunities for numerous studies. The data presented in this paper furnish only a small indication of these possibilities.

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DISCUSSION

B. T. SHAW (Bureau of Plant Industry, Beltsville, Maryland, May 17, 1945)--This paper presents interesting information. The data on percolation, surface-runoff, evapotranspiration, condensation, and absorption will be useful in that they are factual data on actual happenings. The data presented on moisture-storage is interesting but the assumptions on which they are based are too arbitrary to allow much extension of the data to other situations. The authors probably have made a good calibration of the relation between the moisture stored in the adjacent watersheds and the data collected from the lysimeters. It cannot be assumed that the moisture-conditions in the lysimeters will be the same as those in similar horizons in the adjacent soils, and, therefore, it is hazardous to infer the probable moisture-conditions in a portion of the lysimeters. It would have been helpful if the authors had presented the moisture-storage data for the whole lysimeter. This data would have been factual and would have allowed the reader to make such comparisons as he desired.

C. W. THORNTHWAITE (Soil Conservation Service, Washington, D. C., June 14, 1945)--As the authors say, the weighing-monolith lysimeters of the Soil Conservation Service at Coshocton, Ohio, have provided hydrologic data of great value. However, the determinations of the separate elements of the hydrologic cycle vary greatly in reliability, and although in lysimetry the major emphasis is placed on percolation, the measurement of this element is the most unreliable.

Soil-physicists have emphasized for some time that moisture-conditions within a lysimeter are not comparable with those in a natural soil because of the restraining influence on percolation of the interface between soil and air at the base of the soil-columns. NEAL, RICHARDS, and RUSSELL [see 3 of "References" at end of discussion] in 1937 showed that drainage from a lysimeter will not occur unless the lower part of the soil-column is nearly saturated with water, since the force of gravity alone is tending to cause drainage.

WALLIHAN [see 9 of "References" at end of discussion] pointed out that in a well-drained soil in which the water-table is at considerable depth, the energy-gradient due to gravity is supplemented by the energy-gradient resulting from the capillary tension in the soil below. To an extent depending on the magnitude of this supplementary tension, the moisture-content in lysimeter soils is higher than that in similar natural soils.

WALLIHAN conducted an experiment in which two lysimeters were allowed to drain by gravity and a supplementary tension of 136 cm of water was imposed on two others by means of tensiometer-cups installed in their bases. During a 56-day period after initial wetting and while the soils were fallow, the soil-moisture content was lower in the lysimeters under tension and the volume of percolate was five times greater than in those without supplementary tension. WALLIHAN found that evaporation from the moist soil was greater than that from which moisture was reduced by drainage. Oats were grown on two of the lysimeters during the latter part of the experiment. The oats growing where drainage was by gravity alone transpired more and grew much more than those growing on soils where the moisture-content was reduced by supplementary tension.

In the report for 1943-44 of the Committee on Transpiration and Evaporation of the Section of Hydrology, COLMAN [10] described a study in which a tension of 150 cm of water, maintained at the base of a soil-column seven inches in diameter and six feet long, reduced the moisture throughout to a level below field-capacity. He believes that only by applying the proper tension to the soil-water at the seepage-plane can soil confined in a lysimeter be made comparable to a like depth of naturally drained soil. COLMAN'S conclusion would apply to the measurements of percolation of the lysimeters at Coshocton as well as to any others.

Throughout the North Appalachian Plateau, of which the Coshocton Area is representative, the landscape abounds in land-forms which reveal something of the nature of subsurface water-movement. They are associated earth flows and slumps. Those shown in Figure 1 are only a few miles from Coshocton. They develop during or after heavy rain when the soil above the undecomposed rock becomes saturated with water. The water moves downhill through the soil-mass and creates differences in soil-moisture tensions. At lower levels water concentrates in the soil and develops positive pressure sufficient to cause bulging of the sod and flow of earth and mud. While the flow is active, if the sod-roll at the toe of the earth flow is punctured, water will gush out as from a spring. Upslope, the soil-moisture is under negative tension; it must be because the soil is rapidly drained to values below the moisture-equivalent; otherwise the soil would not slump in individual blocks as it does but would flow with the soil below. How great the tension may be is not known but it must be considerable. Usually the subsurface water flows down slope without developing pressure

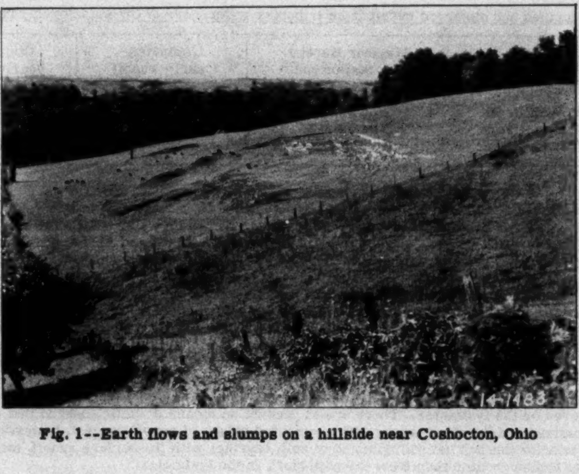

Fig. 1--Earth flows and slumps on a hillside near Coshocton, Ohio sufficient to disturb the soil-surface, but the water down slope exerts a tension on that above so that the soil is progressively drained from the top of the slope to the bottom to moisture-values below the moisture-equivalent.

The Coshocton monolith lysimeters have been constructed on these slopes. Since the lysimeter-walls extend through the soil-mass and for some feet into the solid rock, it is certain that the moisture that enters the lysimeter-soil is deprived of all connection with the subsurface water on the natural slope both above and below. Thus natural drainage is prevented.

There is other evidence that the percolation from the Coshocton lysimeters presented by the authors in their Table 1 is considerably smaller than the percolation through natural soils and that, in consequence, the values of evapotranspiration are too high. The total runoff measured in the streams in east central Ohio, where the Coshocton Experiment Station is located, is consistently several inches larger than the sum of percolation and surface runoff from the lysimeters. Likewise, the difference between measured runoff from the streams and precipitation on the watersheds, which constitutes the loss by evapotranspiration, is several inches less than the evapotranspiration from the lysimeters. If the same amount of water evaporated from undisturbed soil as from the lysimeters, it would be impossible to account for the actual flow of streams in that part of Ohio.

In the report of 1943-44 of the Committee on Transpiration and Evaporation [10], I described a new method of computing evapotranspiration from temperature- and precipitation-data. By subtracting computed evapotranspiration from precipitation, values of total runoff (surface runoff plus seepage) can be obtained, which in turn can be compared with measured values of runoff obtained by stream-gaging. The computed values of runoff compare very closely with measured amounts throughout the eastern United States.

There are three watersheds near Coshocton that are sufficiently large and that possess physical characteristics such that no significant amounts of water flow from them unmeasured. They are Killbuck Creek above Killbuck (466 square miles), Licking River above Toboso (672 square miles), and Wills Creek above Bird Run (730 square miles). Using the records of temperature and precipitation of single Weather Bureau stations centrally located in each of these watersheds, I have computed monthly evapotranspiration and runoff for a number of years. To the extent that the precipitation and temperature registered at the station are not the same as for the watershed, the computed runoff should be expected to differ from the measured runoff. Monthly and annual computed values of runoff are, however, in good agreement with measured values (Fig. 2) and the average values given in Table 1, based on the series of years investigated, are almost identical.

Table 1--Computed and observed runoff from tributary watersheds of the Muskingum Drainage-Basin

Watershed	Weather Bureau Station	Computed yearly runoff	Observed yearly runoff
		in	in
Killbuck Creek	Wooster	10.94	10.24
Licking River	Newark	12.94	12.80
Wills Creek	Cambridge	12.95	12.41

The greatest discrepancy between computed and observed runoff is for the year 1935 in Killbuck Creek, where computed runoff exceeds observed by 5.13 inches. But in that year the precipitation at Wooster was considerably more than that over the whole water shed. The annual precipitation at Wooster was 7.44 inches above normal and that at Ashland and Akron, near the upper end of the watershed, was respectively 2.12 inches and 2.21 inches below normal.

On the whole the computed values of runoff, and therefore of evapotranspiration, for this region are trustworthy. However, the runoff for 1943 and 1944 at Coshocton, computed from Weather Bureau temperature and lysimeter precipitation, is considerably greater, and the evapotranspiration is considerably less, than that given by the authors. Comparative data are given in Table 2.

Computed values of runoff for the two years are 5.46 inches and 5.13 inches greater than measured values, and computed evapotranspiration losses are less by 6.50 inches and 7.14 inches than those observed on the lysimeter. There are at present no means of being assured that one set of values is correct and the other wrong. The computed values of runoff suggest, however, that the annual percolation through natural columns of soil, together with the surface runoff, may be approximately five inches greater than from the soil-block in the lysimeter.

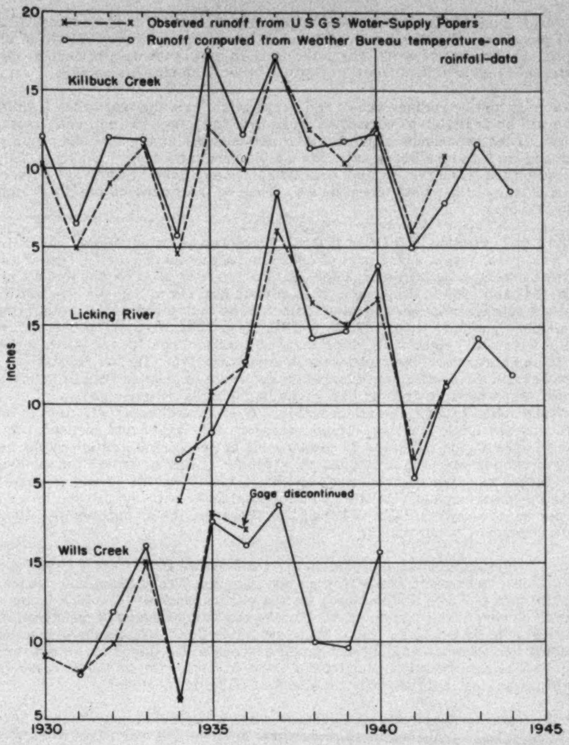

Fig. 2--Annual runoff from tributary watersheds of the Muskingum Drainage-Basin, Ohio

Table 2--Comparative data of precipitation, evapotranspiration, and runoff at Coshocton, Ohio, 1943 and 1944

Item	Computed from climatologic data [a]		Observed on Soil Conservation Service Lysimeter Y103	
	1943	1944	1943	1944
	inches	inches	inches	inches
Precipitation	34.50	35.06	34.50	35.06
Evapotranspiration	22.64	23.23	29.14 [b]	30.37 [b]
Runoff	13.54	10.24	8.08 [c]	5.11 [c]
Potential evapotranspiration	28.62	30.47	....	....
Moisture-deficiency	5.98	7.24	....	....

[a] Temperature-data from Weather Bureau Station at Coshocton; precipitation-data from Soil Conservation Service lysimeter Y103. [b] Condensation is deducted from evapotranspiration to make observed and computed values comparable. [c] Sum of percolation and surface runoff.

Surface runoff from the lysimeters was negligible. According to the authors' Table 1, there was only 0.11 inch of runoff in 1943 and 0.06 inch in 1944 from lysimeter Y103. Thus almost all of the precipitation entered the soil. The authors could supply the data of surface runoff from the adjoining watersheds up to a square mile in extent in their closing discussion.

If less water is lost by surface runoff and percolation from the soil in the lysimeter, more soil-moisture will be available to vegetation there than in the natural soil and evapotranspiration will be greater. If the experience of WALLIHAN can be taken as a guide, the plants growing on the lysimeter and having more water available should produce a larger harvest. The authors say that plant-cover on the lysimeter was not exactly representative of that on the adjacent watershed, but they say it is less, rather than more, dense. They do not report on the dry-weight yields on the two areas, however.

The authors call attention to the fact that the evapotranspiration values that HOLZMAN and I reported for Arlington, Virginia, for part of 1939 are only about one-half as great as those obtained from the Coshocton lysimeters. Although data for 1939 in Arlington are not comparable with those for 1943 and 1944 in Coshocton, it is certain that our values are too small. We have pointed this out a number of times and have indicated the deficiency in our evaporation-equation that is responsible [7, p. 255, 4, p. 287, 8, p. 181, 5, p. 1302, 6, p. 347]. Our later studies of the variation of wind with height have shown that the familiar logarithmic law of wind-distribution is valid only when the temperature lapse-rate is adiabatic. When the air is unstable and the lapse-rate is superadiabatic the coefficient of turbulent exchange is greater than is indicated by the logarithmic law and evaporation is greater than given by the evaporation-equation. Conversely, at night, when condensation occurs, the air is stable and the turbulence-coefficient is smaller than indicated and condensation is smaller. Thus, evaporation is larger and condensation is smaller than our tables for Arlington indicate. Recomputation of evapotranspiration by the current method, using records of temperature and precipitation, gives 20.71 inches for the ten months of 1939, instead of 11.97 inches as originally reported, and 25.35 inches for the 12-month period. This in no way discredits the vapor-transport method of determining evapotranspiration. We now know the deficiency in the basic equation and it is hoped that there may be an opportunity, after the war, to obtain the data necessary to correct it.

The authors' observations of condensation upon and evaporation from a snow-surface demonstrate that this important matter needs further investigation. They found that condensation amounted to 0.10 to 0.18 inch per day, and that evaporation was as much as 0.22 inch in one day. These values appear to be very large. Although we believe our computations of condensation on to a snow-surface at Arlington to be too large, HOLZMAN and I give 0.007 inch as the largest daily value. There is no doubt that as much as 0.22 inch could evaporate in a day from a snow-surface into warm dry air. This might readily occur from a snow-cover in late spring or early summer on the lower slopes of mountains in California, but it seems unlikely in Ohio.

In winter the layer of strong mixing is rather shallow, extending only 3000 to 5000 feet above the ground, and so it has been possible to determine, by means of soundings by balloon at the beginning and end of an interval of time, the amount of moisture added to the atmosphere by evaporation. In this manner LETTAU [2] determined the evaporation from a snow-surface near Leipzig and Dresden on February 14, 1937. On that day a dry continental arctic air-mass occupied the area. Convection was active and there were a few cumulus clouds in the sky. The temperature above the snow-surface was near 32°F. Thus evaporation should have been near the maximum value. The ascent by balloon was made at $11^{h}00^{m}$ and the descent at $15^{h}00^{m}$. The observers made frequent determinations of temperature and moisture with an ASSMANN psychrometer during the entire period. The moisture-content of the atmosphere increased markedly during the period, below 4500 feet, but remained constant all day above that level. The gain in moisture was 670 grams per square meter of snow-surface, and therefore the evaporation was 0.026 inch.. The total for the day could hardly have exceeded 0.04 inch, representing a gain of moisture to the atmosphere of 28 per cent.

One might expect daily amounts of evaporation and condensation to bear a rough proportional relationship to the amount of water in the atmosphere. The process of condensation results in the partial desiccation of the atmosphere. Since its occurrence coincides with periods when turbulent mixing is reduced to a minimum, probably not more than 25 per cent of the moisture-supply could condense in the course of a night. Although the rate of evaporation is inversely proportional to the concentration of water-vapor in the atmosphere, the amount present depends in no small measure on evaporation during the preceding few days. In midsummer the average daily evapotranspiration amounts to about one-sixth to one-eighth of the average total water present in the atmosphere, and during short periods the daily rate may be as much as one-third to one-fourth. Presumably winter rates are comparable.

HOLZMAN [1] computed the total average depth of water in the atmosphere over Ohio to be 0.20 inch in January, 1936. Although the actual water-vapor content for individual days may be much larger or smaller, it can hardly be expected to reach such a value as to permit the quantities of winter evaporation and condensation that the authors report.

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NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 224, 248, 265, 274, 300, and 304)

NOTES

Earthquakes in July and August 1945--The strongest shocks in the United States occurred in South Carolina on July 26, 1945, and in California on August 15, 1945. Seven strong shocks outside the continental limits of the country were located provisionally from instrumental data obtained through the cooperation of the United States Coast and Geodetic Survey, Science Service, Jesuit Seismological Association, and the directors of a special group of seismological stations.

The South Carolina earthquake (34°.3 N, 81°.4 W) on July 26 occurred at $6^h\ 32^m\ 16^s$, Eastern War Time, and reached a maximum intensity of about 5, Modified-Mercalli Intensity Scale. This is just below the destructive level. The shock was centered about 30 miles northwest of Columbia and affected an area of about 15,000 square miles. Several other shocks of the same order of magnitude have occurred in central South Carolina along the Fall Line.

The earthquake in southern California on August 15 occurred at $10^h\ 56^m$. It was felt from the Mexican border to Los Angeles, and inland to Victorville and Twenty-nine Palms. It apparently centered in the sparsely settled country west of Salton Sea, and at some points near the epicentral area caused slight damage.

Ground and air wave tremors from the atomic-bomb blast in New Mexico on July 16 were registered at several seismograph stations.

The seven preliminary epicenters were located as follows, the times being given in Greenwich Mean Time:

	h m	
July 9	16 41.8	Southern Colombia, 1° N, 77° W
July 15	5 35.0	Mariana Islands, 17° N, 145° E
August 2	20 44.8	Off British Columbia, 54°.2 N, 133°.1 W
August 3	4 11.3	Off Colombia, S.A., 4°.4 N, 82°.1 W
August 3	6 34.5	Off Colombia, S.A., 4°.4 N, 82°.1 W
August 10	11 20.3	Guatemala-Honduras, 15°.4 N, 88°.8 W
August 11	0 33.5	Off Colombia, S.A., 4°.4 N, 82°.1 W

OBTAINING LARGE UNDISTURBED SOIL-CORES IN METAL AND TRANSPARENT CYLINDERS

W. E. Goode and J. E. Christiansen

Abstract

Water-spreading for the purpose of increasing the ground-water supply has been practiced to a limited extent in southern California in natural river-channels and on debris-cones and fans where soils are composed primarily of sands, gravels, and cobbles. In the San Joaquin Valley, spreading is contemplated on the valley-floor between the major stream-channels. Here the soils are loamy sands and sandy loams belonging to several soil-series. Some are older alluviums having a hardpan substratum.

As part of a cooperative investigation to determine the feasibility of water-spreading in this area, and the most practical methods of accomplishing this, the Regional Salinity Laboratory has obtained and tested for permeability a number of undisturbed soil-cores.

The first cores were obtained in steel cylinders approximately five inches inside diameter by 40 inches long. These cylinders were equipped with a cutting shoe with cutting edge having a diameter of 3/16 inch smaller than the pipe. The cylinders were jacked into the soil, simultaneously excavating around the outside. At the laboratory the annular space between the core and cylinder was filled with a semifluid mud.

Some difficulty was experienced with this method of sealing, and later the clearance between the core and cylinder was increased and this space filled, in the field, with a dry-sieved soil of low permeability. This method proved quite satisfactory, but probably disturbed the cores to some extent.

Later some "Lucite" cylinders, 4-1/2 inches inside diameter, were obtained. These cylinders were cut into 16-inch lengths. Equipment and methods were developed for obtaining tight-fitting cores in these cylinders which eliminated the need for sealing. These transparent cylinders proved very satisfactory, and had the advantage that the condition of the cores could be observed when taken and during the period of leaching.

The methods and equipment used for obtaining cores in this investigation are described in detail in a paper "Obtaining soil cores for permeability tests" by W. E. GOODE and J. E. CHRISTIANSEN, published in Agricultural Engineering, v. 26, No. 4, pp. 153-155, 1945.

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SHELBURNE FALLS GNEISS DOME, MASSACHUSETTS

Robert Balk

Abstract

The Shelburne Falls gneiss dome, in the eastern Berkshire Hills of northern Massachusetts, consists of amphibolitic metavolcanics, intruded by sills and complex lit-par-lit injection-zones of a quartz-diorite and its associated volatiles. The dome is surrounded on all sides by the Conway schist, of early Paleozoic age.

The dome surface dips outward at gentle angles, and the gneiss-schist contact is conformable, although an original unconformity is suggested in a few places. Sills or apophyses of quartz-diorite in the schist are lacking; neither the distribution of metacrysts nor the mineral composition and texture of the schist show relationships to the gneiss contact. It is concluded that the gneiss complex is older than the Conway schist. On the other hand, both the Conway schist and the gneiss have been silicified near the dome border, and chlorite, muscovite, tourmaline, and a few pegmatites have been introduced near this surface. It seems that these changes occurred during, or soon after, the metamorphism of the Conway sediments. At about the same time a few dikes of quartz-diorite porphyry were intruded into the gneiss and the schist. At least three of them have been tourmalinized, silicified, and micacized.

Tightly compressed, isoclinally folded amphibolite tracts in the gneiss complex, with axes of folds and lineation in many directions, contrast with gently flexed or mildly folded Conway schist in the vicinity of the dome. Axes of folds and lineation pitch off the dome for the most part, although not everywhere in the steepest directions. Inward-dipping "funnel joints" near the dome border, and steep fractures radiating outward from it, attest to the mechanical expansion of the crust during the doming.

The association of amphibolitic metavolcanics with soda-rich igneous rocks, in the gneiss complex, suggests relationships with similar gneissic terranes of southeastern Vermont and southwestern New Hampshire rather than with the microcline-rich gneisses of the crest of the Berkshire Hills.

[Note: The complete paper is to be published in a forthcoming number of the Bulletin of the Geological Society of America.]

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(Abstract received April 26, 1945; presented in full at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945.)

NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 224, 248, 265, 274, 297, and 304)

PERSONALIA

Nevin M. Fenneman, who organized the Department of Geology of the University of Cincinnati in 1907 and whose work in the physiography of the United States is considered monumental, died July 4, 1945, at the age of 79.

Alexander Fersman, Director of the Lomonosov Institute of Mineralogy, Crystallography, and Geochemistry, died May 20, 1945, aged 62. His death, with the loss of Prof. V. I. Vernadsky on January 6, 1945, is a blow to the science of geochemistry and to the geological sciences in the U.S.S.R. Fersman had organized many exploratory expeditions for the Russian Academy of Sciences which led to discovery of important economic deposits, notably the apatites of the Kola Peninsula. His most important memoires, on geochemistry and regional mineralogy, are in Russian, and therefore possibly were not fully appreciated in this country. His studies of the Kola alkaline rocks are outstanding, and his "Scientific study of Russian mineral resources" (1935) is the main source of information on many Russian resources. He received a Stalin prize, was awarded the Order of the Red Banner of Labor, and was a foreign member of the American and British Mineralogical Societies. In 1943 he received the Wollaston Medal of the Geological Society of London.

E. Fischer of Deutsche Seewarte, Germany, died during an aerial attack on Berlin, February 2, 1943.

G. Gilson, Director, Royaume de Belgique, Service de l'Hydrographie, died January 1, 1944.

Theodore Gissler of France, Vice-President of the International Council for the Exploration of the Sea, died in October 1944.

Robert H. Goddard, Member of the Union since 1930 and Chief of Research on Jet-Propelled Planes in the Navy Department, died August 10, 1945, at the age of 62. Mr. Goddard was formerly Professor of Physics at Clark University.

C. Heinrich, Director of German Fisheries, died at Baden-Baden, May 26, 1944.

Jules Jaumotte, Director of the Royal Meteorological Institute of Belgium, was born at Namur, Belgium, April 14, 1887, and died July 6, 1940. He served in World War I, becoming a Major in 1918. He early recognized the importance of photography in reconnaissance-work and created the Photographic Service of Belgian Aviation. In September 1919 he became Director of the Royal Meteorological Institute. In spite of great difficulties he reorganized the Institute's various services into line with the latest meteorological advances including the science of frontalogy and methods of synoptic and dynamic meteorology, employing the new Norwegian technique. Among his other technical improvements were a meteorograph for aircraft, retaining some of the principles of older instruments, and a new type of light radiosonde. With the invasion of Belgium on May 10, 1940, the Royal Meteorological Institute was mobilized immediately. At La Panne, aided by his staff, Director Jaumotte organized the Meteorological Service of the Army. The capitulation on May 28, 1940, ended his mission. On June 1, Jaumotte was seriously injured by the explosion of an aerial torpedo, as were other members of his family; transported to a hospital in Bruges and later to Uccle, Jaumotte passed away on July 6, 1940.

Jaumotte was a member of the Belgium Committee of Geodesy and Geophysics and of the Belguim Commission for the Second International Polar Year (1932-33). He was a member of the Faculty of Applied Sciences at the University of Liége and recipient of many distinctions at home and abroad. By his death Belgium lost an outstanding meteorologist who had done much to raise that science to the high place it occupies in his country.

More complete accounts of Jaumotte's life and scientific work will be found in *Ciel et Terre* [Nos. 6-11, 1940, and No. 3, 1941].--H. D. HARRADON

W. Nellemose of Denmark, Secretary of the International Council for the Exploration of the Sea, died in a German concentration camp November 13, 1944.

Otto Pettersson, founder of the Bornõ Research Station in Sweden, died January 17, 1941.

B. Schults of Deutsche Seewarte, Germany, died May 27, 1944.

M. Siedlecki, Polish oceanographer, died in 1940 in a German concentration camp.

Oscar Sund, Norwegian oceanographer, died during a bomb attack on a passenger boat on October 1, 1943.

H. Thorade, German oceanographer, died after a serious illness

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STRUCTURAL RELATIONS OF PLANES OF LIQUID INCLUSIONS IN THE CRYSTALLINE ROCKS OF THE WASHINGTON (D. C.) AREA

O. F. Tuttle

Abstract

Planes of liquid inclusions are common in the quartz of igneous and metamorphic rocks. The planes have a high degree of preferred orientation, and it is believed that they represent fractures in the quartz grains that have been filled with intergranular liquid which subsequently changed to individual inclusions by differential solution and deposition of silica. The planes of inclusions commonly extend through several quartz grains of different orientation with no deflection at the grain boundaries, indicating that there is little or no crystallographic control of their orientation.

The orientation of the planes is measured in thin section by turning the planes to vertical on the universal stage. Statistical representation of the poles to planes of liquid inclusions on the SCHMIDT net gives diagrams that are very similar to mica diagrams in a well-foliated schist. Maxima up to 45 per cent have been found, and maxima of 20 per cent are common. Single, strong maxima are most common, but double maxima have been found repeatedly. In the Washington Area, two or more distinct maxima have been found only in quartz veins. In other areas, two or more maxima are apparently common.

The planes of inclusions have been found to have a remarkably uniform orientation over an area of 15 by 20 miles. They strike northwest and dip steeply to the northeast through the area, whereas the primary structures, contacts and foliations strike north-south and dip westward, indicating that the planes of liquid inclusions have been superimposed on the primary structure.

Detailed work on drag-folds indicates that the planes of inclusions develop in the shear-directions of the deforming stress-pattern and that one set tends to predominate. The poles to the planes tend to lie in a partial girdle about the fold-axis.

If several sets of planes of liquid inclusions develop at different times, the relative ages of the planes can be discerned from the character of the planes. Planes of inclusions that are very "young" appear as extremely thin sheets of liquid, whereas "old" planes are made up of inclusions that are nearly equant, with some of the inclusions having crystal planes as boundaries (negative crystals).

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(See also pp. 190, 203, 212, 216, 240, 266, 314, and 324)

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POSTWAR STUDY OF EXPERIMENTALLY DEFORMED ROCKS

Eleanora Bliss Knopf

Abstract

Fundamental research into the mechanism of rock deformation should start with a study of the mechanism of deformation in the ionic crystals that comprise the rock-making minerals. Calcite is recommended as it is probably the easiest rock-making mineral to deform.

The crystal selected for the work should be free from all trace of twinning and lattice distortion as far as can be determined from external appearance, optical investigation, and X-ray analysis. In the first experiments the orientation of the crystal in the testing apparatus should be arranged so as to give the simplest possible symmetrical application of the maximum resolved shearing stress upon the theoretically predicted or actually known glide-planes. [Glide planes are here used to denote crystal lattice planes upon which the crystal is known to slip, either by twin-gliding, which is simple homogeneous shear in one direction sense for a finite, computable distance, or by translation gliding, which is a relative displacement (not necessarily homogeneous) by which layers of the crystal lattice can slide over one another in both senses of a prescribed direction and for an indeterminate distance.]

In order to distinguish between twinning and translation, the crystal should be set up in one set of experiments so as to allow twinning to function and in another set so as to inhibit twinning and restrict gliding movement to translation.

Knowing the orientation of the crystal lattice in its relation to the stress field of the experiment, it should be possible to predict the changes in orientation that would result from successive generations of mechanical twins if the deformation obeys the Law of Maximum Resolved Shearing Stress. Moreover, it should be possible to predict the way in which translation glide-planes would tip in toward the axis of tensile stress or away from the axis of compressive stress. Comparison of the predicted and observed results should give an insight into the mechanism of deformation.

Similar methods of investigation can be applied to polycrystalline monomineral aggregates by deforming a fabric of simple pattern and a fabric of random orientation if such can be found. A fabric of random orientation should be isotropic in the polycrystalline field and the mechanism of deformation should be controlled by the anisotropy of the field of the individual grain. A fabric of simple pattern and relatively strong degree of preferred orientation should show, after deformation, a statistical preference for a concentration of operative gliding planes (preferred orientation) that is controlled by the pre-existent pattern of the undeformed fabric.

Deformation should be stopped at various stages in the deformation of the single crystal in order to compare the changes in fabric at various stages of strain in compression or in tension. It should also be stopped at various stages in deforming a polycrystalline fabric in order to determine the relation between the degree of preferred orientation in the deformed fabric and the amount of strain in the test piece.

In all these experiments the pressure-temperature conditions should be held constant. The orientation of the test cylinders, both in single crystal and in polycrystalline deformation, should then be changed in order to study the possible operation of other glide planes in the crystal lattice.

Later, pressure-temperature conditions should be changed, first singly and then together, in order to study their effect upon grain gliding and also upon recrystallization. Experiments should also be carried on in the presence of volatile constituents, such as water and carbon dioxide in order to study the process of recrystallization and its influence upon preferred orientation.

Finally, as the work progresses, it should be possible to investigate the behavior of single crystals and monomineral aggregates in shearing stress and also to examine the behavior of polymineral aggregates made up of two or more constituents.

It is particularly important, in order to get sound conclusions from this experimental work that the investigation should be carried on systematically, step by step, starting with the simplest possible fabric in single crystals and polycrystalline aggregates, under a very simple stress plan so that we can formulate sound procedures from the fundamental data as a basis for further investigation.

It might be helpful, as scientific research resumes after the war, for the Committee on Experimental Deformation of Rocks of the National Research Council to act as a sort of clearing house for projects that may be started by independent investigators. In this way it might be possible to avoid undesirable reduplication in preliminary experiments and to stimulate simultaneous research along extended lines in various laboratories.

[Note: The complete paper is to be published in a forthcoming number of Science.

New Haven, Connecticut

(Abstract received September 17, 1945; presented in full at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945.)

NOTES AND PERSONALIA

(See also pp. 196, 200, 204, 219, 223, 224, 248, 265, 274, 297, and 300)

PERSONALIA

Kenneth L. Sherman of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to atmospheric electricity.

Otis W. Swainson of the United States Coast and Geodetic Survey has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to the determinations of the velocity and ray paths of sound waves in sea water and to topographic surveying.

Merle A. Tuve, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington who has been on special War work with the Office of Scientific Research and Development, has recently been cited by the Navy Department for his direction of the work in the development of the radio proximity fuse. This fuse has been acclaimed as very effective in the shooting down of German "buzz-bombs" over England in 1944, and more recently in the destruction of Japanese "Kamikaze" planes before they reached their mark.

T. Wayland Vaughan has been awarded the Mark Clark Thompson medal and honorarium of the National Academy of Sciences for 1945 in recognition of outstanding achievement in his purposeful and ingenious coordination of observations and generalizations made in and bearing on the fields of stratigraphic geology and paleontology.

Ernest H. Vestine of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to geomagnetism.

Harry W. Wells of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to ionospheric research.

Charles A. Whitten of the United States Coast and Geodetic Survey has recently been elected to resident membership in the Washington Academy of Sciences in recognition of contributions to the science of geodesy and to practical astronomy.

William E. Wrather, Director of the United States Geological Survey, has recently been elected to resident membership in the Washington Academy of Sciences in recognition of his stimulating influence in geology and other sciences.

F. E. Wright of the Geophysical Laboratory, Carnegie Institution of Washington, has been given a citation by the War Department for his aid to the optical glass program.

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RECENT PROGRESS IN GEODETIC SURVEYS OF THE UNITED STATES COAST AND GEODETIC SURVEY

H. W. Hemple

Abstract--During the year prior to June 1, 1945, the field-surveys of the Division of Geodesy of the United States Coast and Geodetic Survey consisted of triangulation, leveling, base-measurement, and astronomic observations in western Alaska, the Pacific Coast States and several of the southwestern, central and southeastern States. In general, the surveys made were of interest to the military organizations. Because of conditions of the emergency resulting from the war, no gravity-observations have been made during this period.

Horizontal control

The triangulation-surveys in Alaska (Fig. 1) accomplished during the year comprised an arc along the Glen Highway from Anchorage to Gulkana on the Richardson Highway, and an arc along the Tok Highway from Gulkana to Mentasta Pass in the Nutzotin Mountain Range. An arc was also completed from Wide Bay to Chignik Bay along the Alaskan Peninsula. To the westward the triangulation-surveys were extended to Nome and from Port Teller to Cape Prince of Wales and to Little Diomede Island.

The triangulation accomplished in Alaska this year has permitted the North American datum of 1927 for the horizontal control to be extended to the Little Diomede Island, Bering Straits, and to Kiska Island in the Aleutian Islands at 178° east longitude. There is now a scheme of continuous triangulation from the southern end of Mexico through the United States, Canada, and Alaska to the western islands of the Aleutian Island group, a distance in excess of 6,500 miles. This control is also continuous to the eastern end of Newfoundland.

It is hoped that eventually the Union of Soviet Socialist Republics may extend their scheme of triangulation through Siberia and provide a connection at Bering Straits to the stations established by this Bureau on the Little Diomede Island. Ultimately, possibly continuous triangulation will be provided from the North American Continent through Asia to Europe and Africa, and from North America to South America.

Radio communication between observers, lightkeepers, and chiefs of parties in Alaska, using portable short-wave transcievers, proved a successful innovation and enabled scheduling of independent activities to be correlated so as to effectuate the common objective of obtaining triangulation-observations efficiently and economically.

In the United States (Fig. 2) triangulation-control was extended along the Snake River from Weiser to Hagerman, Idaho. The work in the Columbia River Basin is being done at the request of the Corps of Engineers and is in connection with their plans for flood-control, navigation, and water-power development. The control in this region is now underway, and will be augmented on July 1, 1945, when anticipated additional appropriations become available, and more field-parties will be placed in operation.

Triangulation was also executed in Nevada along longitude 114°30′ between latitudes 36°30′ and 41°00′, including the Meadow Wash Area. This work was requested by the United States Grazing Service and the Nevada State Highway Department.

Triangulation was also completed in the Salinas River Valley in southern California and a revision survey of the triangulation in Coos Bay, Oregon, is now underway. Both of these were requested by the Corps of Engineers.

Triangulation-control was established in the Ohio River Basin along longitude 81°30′ from Cleveland, Ohio, to Charleston, West Virginia, and along latitude 39°30′ from Clarksburg, West

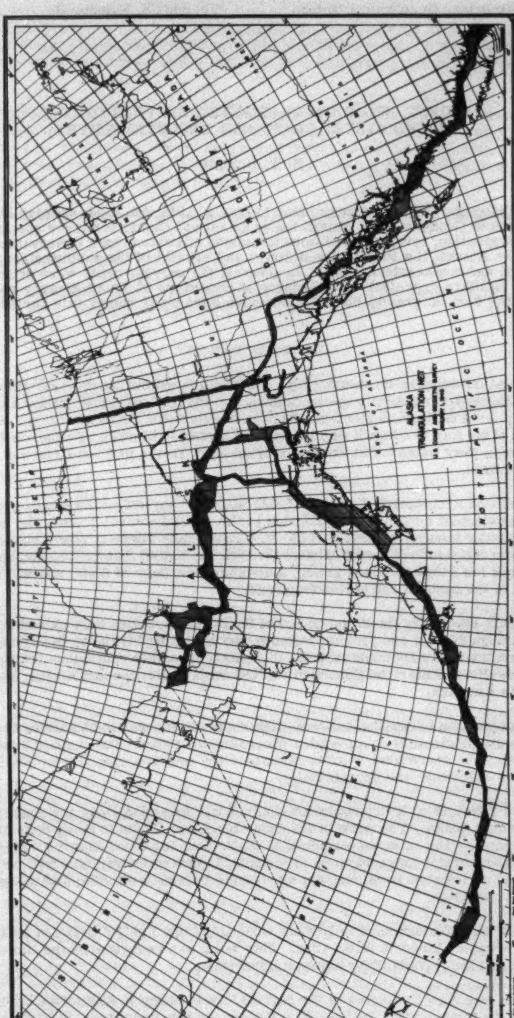
ALASKA
TRIANGULATION NET
U.S. COAST AND GEODETIC SURVEY
JANUARY 1, 1945
ARCTIC OCEAN
DOMINION OF CANADA
NORTH PACIFIC OCEAN
GULF OF ALASKA
ALASKA
BERING SEA
SIBERIA

Fig. 1--Triangulation-net, Alaska, January 1, 1945

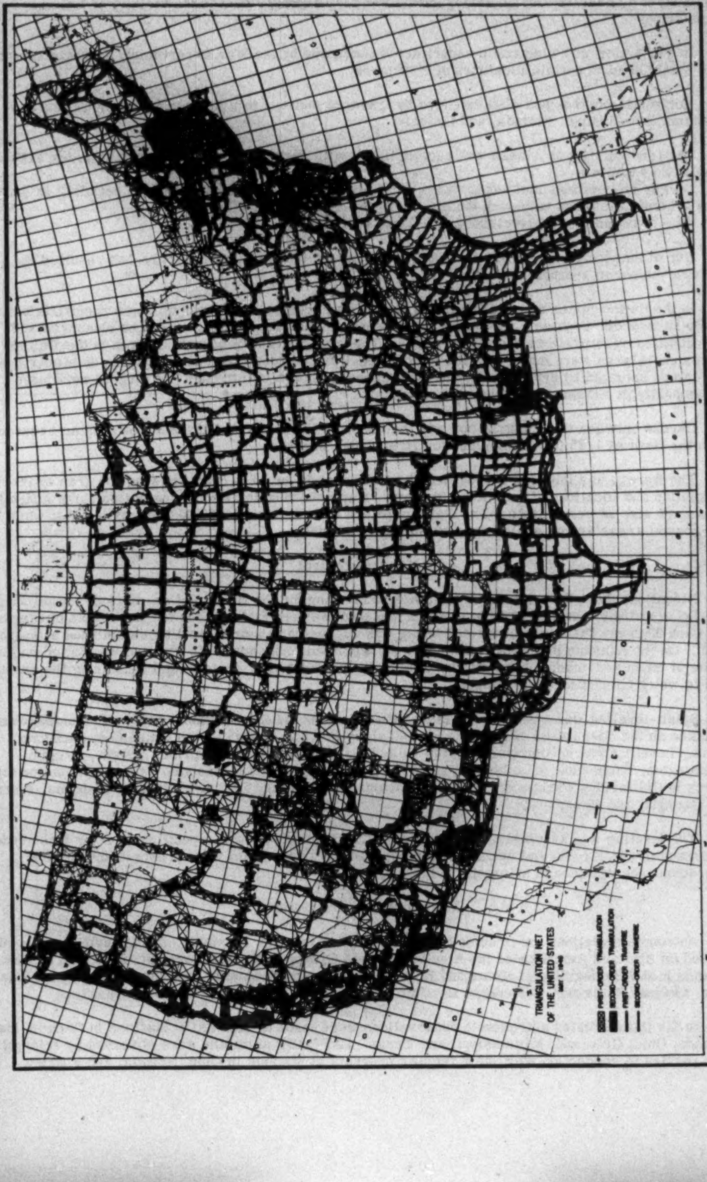
TRIANGULATION NET
OF THE UNITED STATES
MAY 1, 1945
FIRST-ORDER TRIANGULATION
SECOND-ORDER TRIANGULATION
FIRST-ORDER TRAVERSE
SECOND-ORDER TRAVERSE

Fig. 2--Triangulation-net, United States, May 1, 1945

Virginia, to Lancaster, Ohio. Triangulation was also accomplished in the vicinity of Jackson, Mississippi.

In connection with electronic experiments conducted by the War Department, accurate control was established in certain localities of New Jersey.

Horizontal control was also extended by traverse surveys to a number of major airports in Alabama, Mississippi, Florida, and Georgia.

The triangulation in Alaska was accomplished with specifications to attain first-order accuracy, modified as follows:

(a) For 16 positions measured with a first-order theodolite any observation deviating in excess of 5″ from the mean value for the direction was reobserved.

(b) A maximum triangle closure of 4″ was acceptable.

Use of these criteria for the work in Alaska during the past several years has resulted in triangle-closures averaging 1″.20.

In the United States most of the triangulation was accomplished with standard specifications to attain first-order accuracy, although several schemes of triangulation were also measured with the modified specifications mentioned above. The triangulation-observations both in the United States and Alaska were made with the PARKHURST first-order theodolite, sighting on electric signal-lamps actuated by dry-batteries in most cases, although heliotropes and targets were used occasionally in Alaska during the early summer.

Checks between the triangulation and the measured bases invariably were of greater accuracy than the limit of 1/25,000 prescribed for first-order surveys.

The Bureau has initiated a program of printing maps for each State showing the arcs of triangulation and locations of individual stations. Maps showing detailed triangulation along coastal areas are also in preparation. The State maps are on a scale of 1:800,000 approximately; while the coastal areas are on scales approximating 1:120,000.

Vertical control

Elevations were determined by trigometric leveling for the triangulation-stations established in Alaska and the mountains of the western and southwestern States. For the mountains bordering the Glen Highway the trigonometric leveling was connected to spirit-leveling established along the road. On the Alaskan Peninsula and on Seward Peninsula trigonometric leveling was based on the plane of mean sea-level determined by tide staffs established at certain intervals along the coast and to which connections were made.

Spirit-leveling was executed in Alaska (Fig. 3) along the Glen Highway between Anchorage and Gulkana on the Richardson Highway, and also along the Tok Highway from Gulkana to Mentasta Pass. Leveling was accomplished in the United States (Fig. 4) in California, Nevada, Oregon, Washington, Tennessee, Mississippi, and West Virginia. Leveling was also extended to major airports in California, Washington, Oregon, Arizona, Idaho, Utah, Texas, Louisiana, Alabama, Florida, Georgia, and Mississippi.

The leveling was accomplished with the FISCHER precise level. Specifications for first-order accuracy of $(4\sqrt{K})$ mm and second-order accuracy of $(8\sqrt{K})$ mm were prescribed, where K represents the distance in kilometers.

Astronomic determinations

Astronomic stations for precise determinations of latitude, longitude, and azimuth were established on Attu and Amchitka of the Aleutian Islands Group, on St. Matthews, St. Paul, and St. George islands in the Bering Sea, at Nome and Kotzebue on Seward Peninsula in western Alaska, at Wide Bay, Alaskan Peninsula, at Redoubt Bay in Cook Inlet, and at Circle in western Alaska.

In the United States astronomic observations were made at LAPLACE stations in Oregon, Idaho, Nevada, Ohio, Colorado, Mississippi, and Texas. LAPLACE azimuths were observed by triangulation parties in connection with their regular program at stations in Ohio, Nevada, and Florida.

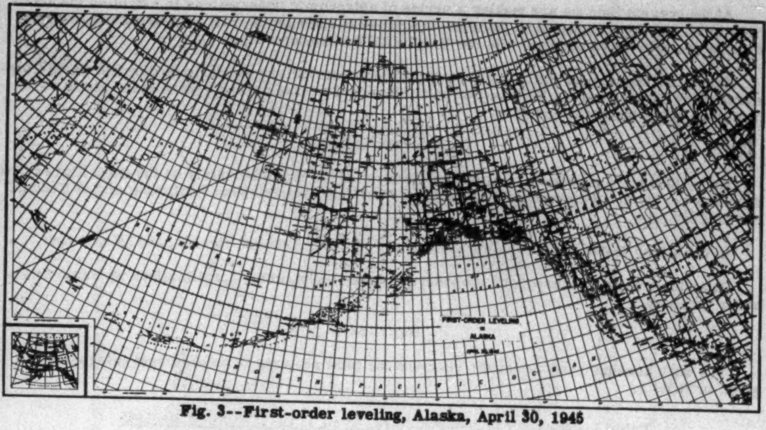
FIRST-ORDER LEVELING
IN
ALASKA
NORTH PACIFIC OCEAN

Fig. 3--First-order leveling, Alaska, April 30, 1945

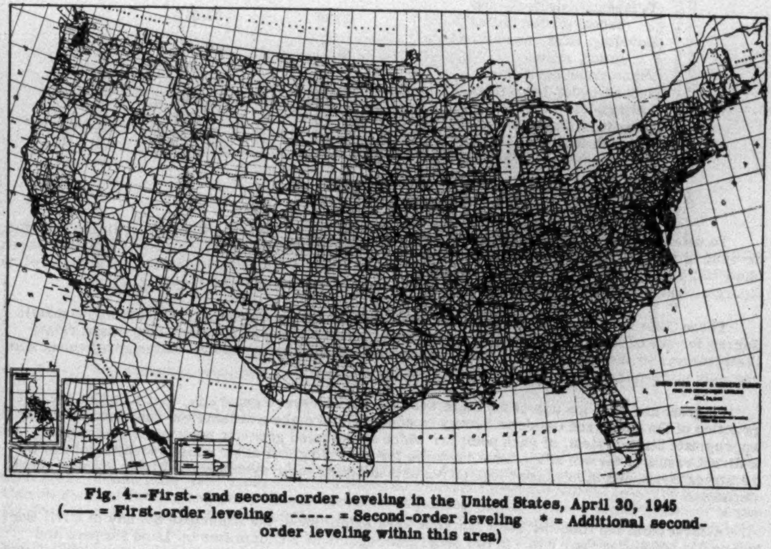
GULF OF MEXICO
UNITED STATES COAST & GEODETIC SURVEY

Fig. 4--First- and second-order leveling in the United States, April 30, 1945 (—— = First-order leveling ----- = Second-order leveling * = Additional second-order leveling within this area)

At the present time we are making a series of astronomic observations to establish the accuracy which may be anticipated by using several types of instruments and comparing the results with the precise values obtained with the BAMBERG broken telescope.

Scientific time signals for use in the astronomic observations are furnished by the Naval Communications Service and the National Bureau of Standards. The corrections to these signals are furnished by the Naval Observatory.

Base-measurements

Base-lines were measured in Alaska as follows: Near Sheep Mountain on the Glen Highway; at Kotzebue and Nome on the Seward Peninsula; at Nakalilok Bay, Alaskan Peninsula; and at Redoubt Bay in Cook Inlet.

In the United States base-lines were measured in Ohio, Arizona, Nevada, and Mississippi.

Base-lines were measured with ribbon-type, invar tapes, using specifications to obtain first-order accuracy.

Statistics

The work accomplished during the year and the total amounts in the different categories are given in Table 1.

Table 1--Summary of geodetic work, April 1, 1944, to April 30, 1945

Work	Completed 1944-45	Total
Triangulation, first- and second-order, miles	2150	97,015
Leveling, first- and second-order, miles	4072	330,704
First-order base-lines	12	265
Second-order base-lines	0	55
Latitude-stations	14	989
Longitude-stations	16	791
Azimuth-stations	18	1,272

State plane coordinates

To date legislation has been passed authorizing the use of the State Plane Coordinate Systems devised by this Bureau for property-description purposes in the following States: Vermont; Massachusetts; Rhode Island; New York; New Jersey; Pennsylvania; Delaware; Maryland; North Carolina; Georgia; Louisiana; Texas; Minnesota; Nevada; Oregon; and Washington (see Fig. 5).

These State Plane Coordinate Systems were devised by the United States Coast and Geodetic Survey for use of local engineers and surveyors to furnish a means by which they might relate their surveys to the rigid net of control-surveys established by the United States government and use only plane-surveying methods and formulas.

So great has been the use of the State systems by surveyors generally, that it is the present practice of the Coast and Geodetic Survey to compute and make available the coordinates on the appropriate State system, of each point for which an adjusted geodetic position is determined. As a direct result of the use of the State systems for surveying and describing land-boundaries, the 16 States mentioned have passed legislative acts adopting their systems and giving them precise definition.

Almost from the time the State systems were established, the American Society of Civil Engineers has advocated their use. In two progress-reports of a Committee on Land Surveys and Titles, the legislative adoption of the State systems has been strongly recommended. This Committee is a Joint Committee of the Real Property Division of the American Bar Association and the Surveying and Mapping Division of the American Society of Civil Engineers. These progress-reports were published in the Proceedings of the American Society of Civil Engineers for

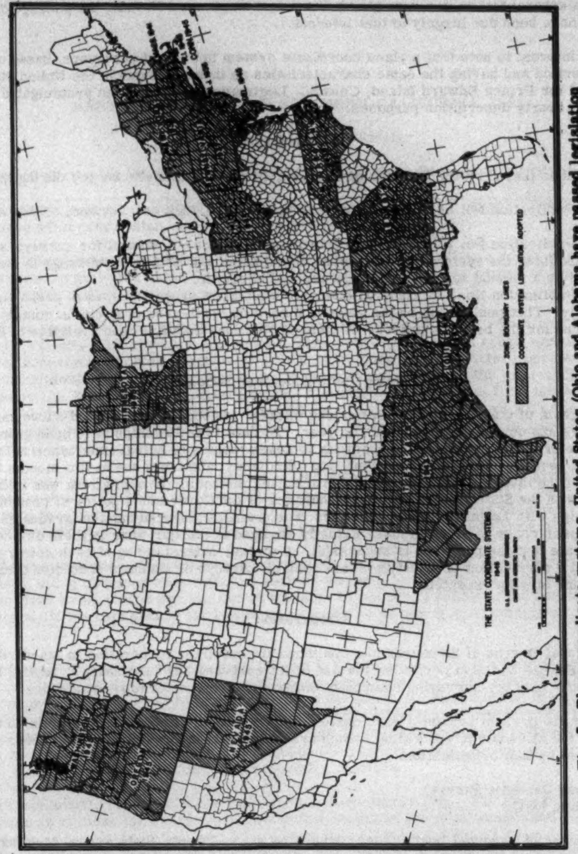
THE STATE COORDINATE SYSTEMS
1945
ZONE BOUNDARY LINES
COORDINATE SYSTEM LEGISLATION ADOPTED

Fig. 5--Plane coordinate systems, United States (Ohio and Alabama have passed legislation authorizing the use of State Plane Coordinate Systems since this paper was presented.)

November, 1938, and June, 1941.

Early in 1943, at the request of the above Joint Committee, the Coast and Geodetic Survey prepared bills for the adoption of their coordinate systems by several States which did not yet have such laws. These bills were cleared with interested Federal Departments and referred to the Section on Federal-State Relations of the Department of Justice which, in turn, presented them to the Drafting Committee of the Council of State Governments. The Council approved the proposed legislation and included it in its report on suggested State, War, and Postwar Legislation for 1945. The active sponsorship of this legislation in the various States was largely by the State and local sections of the American Society of Civil Engineers.

The interest taken in this legislation by members of State highway departments was very noticeable. In several States, for example, Delaware, Georgia, and Nevada, the passage of the legislation may have been due largely to that interest.

It is of interest to note that a plane coordinate system for use of surveyors, based on the LAMBERT projection and having the same characteristics as those in vogue in the United States, has been adopted for Prince Edward Island, Canada. Legislation has also been promulgated authorizing its use for property description purposes.

Publications

Publications issued by the Division of Geodesy, Coast and Geodetic Survey during the year were:

Special Publication No. 68, Elements of map projections, fifth ed., revised, of this authoritative treatise.

Special Publication No. 235, The State coordinate systems--A manual for surveyors. This publication explains the systems of state plane coordinates and details their usage in simple terms. It is intended as a manual for the local engineer and surveyor.

Special Publication No. 236, General theory of equivalent projections, is in press and will be issued shortly. This publication on the general theory of equal-area projections contains many useful features for the better knowledge of these projections than has been available in English heretofore.

Training Latin American nationals

The program of training of Latin American citizens in geodesy and related surveying and mapping activities has continued throughout the year. To date 12 fellowships have been granted in geodesy. The program contemplates from six to seven months of actual experience in the field on triangulation, leveling, base-measurement, and astronomy, and from one to two months in the Washington office studying adjustments and processing methods. This program was initiated in cooperation with the State Department in furtherance of the Government policy of promoting friendly relationships with Latin American countries. The trainees selected must be graduates in engineering and preference is given to those actually engaged in similar work in their own countries. Results indicate that the program is successful. A mutual understanding of each country's survey problems and a correlation of effort to obtain control-surveys of standard precision throughout the hemisphere may be expected.

Cooperation

The National Bureau of Standards has continued its excellent cooperation in standardizing base-tapes. That Bureau has also permitted the use of its cold-weather laboratory in testing the performance of our precise-surveying equipment under extreme temperature-conditions.

Plans for the present season's work contemplate extensive surveys in the Columbia River Basin and in the Missouri River Valley, which are of interest to the Corps of Engineers and have been requested by that organization.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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Transactions, American Geophysical Union **Volume 26, Number II** **October, 1945**

EARTHQUAKE STUDY IN SOUTHERN CALIFORNIA, 1944

B. Gutenberg and C. F. Richter

(Contribution No. 382, Balch Graduate School of the Geological Sciences)

This continues a previous report [see 1 of "References" at end of paper]. Three papers, previously named as in preparation, have now appeared [2, 3, 4].

Study of travel-times for southern California has been rounded off by a paper on minor phases [5]. Certain waves reflected at the 33-km level are strong over limited ranges of distance, in accordance with theoretical expectation.

Results on amplitudes are included in a more general paper [6]. The velocity of $\overline{P}$ in km/sec is given by $v = (5.56 + 0.001h)$ where h is in km. The coefficient of h is a rough approximation only; it indicates increase in the bulk-modulus of elasticity by about three-quarters per cent for a pressure of 1,000 atmospheres. Similar increases in velocity are found for the intermediate crustal layers. Below the MOHOROVIČIĆ discontinuity, velocities of P and S at first increase with depth, but the rate of increase falls off rapidly. Near 80 km the velocity decreases with depth, producing a shadow-zone of small amplitudes for P and S. This disappears when the focus is deeper than about 250 km [13].

Energy-partition among reflected and refracted waves at discontinuities is given a general theoretical discussion [7] which includes many calculated numerical examples. Special values for the surface of the core [8] are used to compute amplitudes for core waves reaching the surface [9]. A theoretical study of modes of generation of seismic waves has been published [10].

To improve statistics of seismicity the magnitude scale for distant, shallow earthquakes has been revised, using observed amplitudes of surface waves [11]. These correspond closely to an absorption given by k = 0.0002 per km except for loss of energy in crossing the boundary of the Pacific Basin. If the path grazes the boundary as much as 90 per cent of the energy may be scattered.

To extend the magnitude scale to deep shocks it was necessary to study amplitudes of the principal phases (P, PP, S) for shallow shocks of known magnitude [12]. The absorption-coefficient for longitudinal and transverse waves in the interior of the Earth is about 0.00012 per km. Energy leaving the focus divides about equally between longitudinal and transverse waves. Tables of amplitudes of P, PP, S as functions of distance now can be used in conjunction with data on surface waves to determine magnitudes. For this purpose the reports of stations which give amplitudes for P, PP, S, etc., as well as of maxima, are especially valuable.

These tables and results have been extended to deep shocks [13]. The magnitude of a deep shock is so defined as to make the energy released in two shocks of the same magnitude equal, regardless of focal depth. Magnitudes of 7-3/4 to 8 have been found throughout the range of focal depth; but during the last 40 years these seem to have been less frequent in deep than in shallow shocks, relative to smaller magnitudes. (The greatest known shock with depth over 200 km was that of January 21, 1906, in Japan--magnitude 8. The shock of May 26, 1932, at a depth of 600 km, south of the Fiji Islands, had a magnitude near 7-3/4.) Apparently at depths over 150 km only roughly one-tenth as much energy can be stored as at depths between 15 and 40 km.

Investigation still in progress is being partly reported in a second paper on the seismicity of the Earth [14] which includes new maps and tables of located shocks. About 70 great earthquakes have now been identified for 1904-43 and about 200 major earthquakes for 1922-43. Mechanism of Pacific structural arcs is discussed in connection with the geographical order of the associated features and phenomena.

Compilation of as complete a catalogue of large earthquakes as is possible for the years 1904-22 is under way. A special study of earthquake activity in California includes lists of the larger recent

shocks [15]. H. O. WOOD is preparing a study of the local epicenters thus far located, in their relation to the known fault-structure. J. M. NORDQUIST has reported on his statistical investigations [16]. A beginning has been made on study of all disturbances, large or small, recorded during a selected week. Routine bulletins covering all but the smallest local shocks, and all teleseisms recorded, have been prepared through 1944.

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Transactions, American Geophysical Union Volume 26, Number II October, 1945

PROGRESS-REPORT OF THE JESUIT SEISMOLOGICAL ASSOCIATION FOR 1944

James B. Macelwane

War conditions have continued to affect seriously the work of the member stations of the Jesuit Seismological Association during the year 1944. Nevertheless, reports of earthquakes were received at the Central Station in Saint Louis from the seismological stations at the following Jesuit colleges and universities: Canisius College, Buffalo; Loyola University, Chicago; Xavier University, Cincinnati; Regis College, Denver; Fordham University, New York; Georgetown University, Washington; Mount Saint Michael's, Spokane; Loyola University, New Orleans; University of Santa Clara, Santa Clara; Spring Hill College, Spring Hill; Weston College, Weston; and from the Saint Louis University cooperative stations at Cape Girardeau and Florissant, Missouri, and Little Rock, Arkansas.

It is impossible to overestimate the value of the cooperative agreement between Science Service, the United States Coast and Geodetic Survey, and the Jesuit Seismological Association, which has been operative since 1925, in the immediate determination of epicenters. Through the cooperation of the United States Navy extremely valuable information from outlying stations has continued to be made available.

In the course of the year 48 numbers of the Preliminary Bulletin were issued by the Central Station. In these Bulletins were published the locations of epicenters, depths of focus, and pertinent station reports of the 48 earthquakes listed in Table 1. Thirteen of these earthquakes--all in the Pacific or circum-Pacific Area--were deeper than normal; one, near the Kermadec Islands, had a focal depth of the order of 600 km.

Table 1--Summary of "Preliminary Bulletins on Epicenters"

Bull. No.	Date	Latitude	Longitude	H* G. C. T.	Depth	Remarks
	1944	°	°	h m s	km	
1	Jan. 15	31.5 S	67.6 W	23 49 26	?	San Juan, Argentina
2	Jan. 10	16.4 N	100.3 W	20 09 50	?	
2	Jan. 10	16.4 N	100.3 W	20 33 20		
3	Feb. 1	40.3 N	30.9 E	03 22 45	Normal	Turkey
4	Feb. 3	60.5 N	137.0 W	12 15 02		Whitehorse, Canada
5	Feb. 29	13.7 S	70.6 W	03 42 09	275 ±	
6	Feb. 29	0.5 N	75.5 E	16 28 08		
8	Mar. 9	46.7 N	85.4 E	22 13 24		
9	Mar. 22	8.0 S	123.0 E	00 43 05	100 ±	
10	Mar. 31	0.0 ±	80.0 W	......		
11	Apr. 26	1.0 S	131.0 E	01 54 05	?	
12	Apr. 27	1.0 S	131.0 E	14 38 00	?	
13	Apr. 7	12.2 N	85.2 W	13 32 50	Normal	
13	Apr. 19	25.0 S	115.9 W	......	?	
14	May 6	23.0 N	44.5 W	00 13 43		
15	May 25	25.0 S	179.4 E	01 06 21	600 ±	
16	May 25	2.0 S	150.4 E	12 58 00		
17	May 18	1.5 S	151.0 E	04 43 14		
17	May 19	1.5 S	151.0 E	00 19 14		
18	June 16	18.3 N	104.8 W	21 51 28		
19	June 21	21 S	169 E	10 58 20		
20	June 25	1.0 S	24.8 W	17 42 22		
21	June 28	14.3 N	92.7 W	07 58 50	Normal	
22	June 3	20 N	64 W	07 12 20		
23	July 12	44.5 N	114.5 W	19 30 22		
24	July 19	33 N	140 E	10 21 18		
25	July 27	54 N	164.8 W	00 04 30	80-100	

Table 1--Summary of "Preliminary Bulletins on Epicenters"(Concluded))

Bull. No.	Date	Latitude	Longitude	H* G.C.T	Depth	Remarks
	1944	°	°	h m s	km	
26	July 2	13 N	97.5 W	22 12 08		
26	July 22	17 N	94 W	11 28 34		
27	Aug. 7	15.3 S	73.8 W	03 25 33		
28	Aug. 10	51 N	131 W	01 52 48		
29	Aug. 24	15.5 N	93.6 W	23 37 51	80	
30	Aug. 14	53 N	148 W	. . . . . .		
32	Sep. 11	7.0 S	131.3 E	09 45 17		
33	Sep. 23	53.2 N	162.0 E	12 13 28	50 ±	
34	Sep. 3	54.5 S	125.0 W	19 11 43		
34	Sep. 27	39 N	74 E	16 25 08	?	
35	Oct. 2	14.2 N	90.1 W	17 21 58	150	
36	Oct. 2	43.5 N	141.7 E	20 29 57	100	
37	Oct. 5	5.0 S	127.0 E	16 51 44	Deep	
37	Oct. 5	19 S	169 E	17 28 27	100 ±	
38	Oct. 6	40.0 N	29.3 E	02 34 40	?	
39	Oct. 23	0.3 S	80.2 W	23 40 01	?	
40	Oct. 11	15.0 S	172.5 W	9 45 16	80 ±	
41	Nov. 15	4 N	128 E	20 47 04		
42	Nov. 16	12,1 S	166.1 E	12 10 59		
43	Nov. 24	18.5 S	169.0 E	4 49 00	100	
45	Dec. 7	33 N	137 E	04 35 46	?	Japan
46	Dec. 10	18.5 S	168.5 E	16 25 01		
47	Dec. 12	52.0 N	176.7 W	04 17 24		
48	Dec. 5	25 N	110 W	14 41 22		
48	Dec. 5	25 N	110 W	17 09 20		
48	Dec. 22	25 S	70 W	22 32 03	150 ±	

* Origin time at hypocenter.

In September, 1944, the headquarters of the Central Station of the Jesuit Seismological Association were removed from 15 North Grand Boulevard to a more commodious laboratory in the Saint Louis University Institute of Geophysical Technology at 3621 Olive Street.

It is hoped that, in the course of the year 1945, the instrumental equipment at Denver, New Orleans, and Saint Louis may be improved. A first-class station equipped with two newest type long-period, horizontal-component Sprengnether seismometers, a short-period, vertical-component Sprengnether seismometer, and a new type triple-drum will be installed by Loyola University in New Orleans. The instruments are already in process of construction. Two of the newest type Sprengnether 20-second horizontal-component seismometers have already been delivered for installation in the Gymnasium vault at Saint Louis University.

Jesuit Seismological Association,
Saint Louis University,
Saint Louis, Missouri

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OCEANOGRAPHIC ACTIVITIES OF THE COAST AND GEODETIC SURVEY DURING THE PAST YEAR

L. O. Colbert

The prolongation of the war has forced a continued curtailment of the oceanographic activities of the Coast and Geodetic Survey. At the beginning of the war six major vessels of this Bureau were transferred to the Navy, with only one replacement made during the spring of 1944. During the past year three major survey-ships and three small vessels operated in Alaskan waters under the direction of an officer of the Coast and Geodetic Survey attached to the Naval District Headquarters as liaison officer between that District and the vessels of this Bureau. On the east coast one survey-ship and five small vessels were in operation. In connection with the hydrographic work being accomplished by all of these parties, observations of temperature and salinity were taken in the areas being surveyed. All offshore radio-acoustic hydrographic work, which was under way at the beginning of hostilities, was discontinued and all work has been limited on the east coast to harbors and inside waters, being confined principally to surveys requested by the Armed Forces. In Alaska all surveys were confined to areas of strategic military importance.

During the past winter current-surveys initiated several years ago were continued in Puget Sound with the new radio-current-meters. These meters continue to demonstrate the advantages of this method over old methods, furnishing better observations at greatly reduced cost. Minor improvements are being made in new meters now under contract. The British Admiralty has recently purchased one of these meters in the United States with a view to introducing the method in England.

Experiments are being conducted with radar and other electronic devices, outgrowths of World War II, with a view to supplementing radio-acoustic-ranging for position determination in offshore hydrographic surveying.

A revised edition of the Hydrographic Manual [Spec. Publ. No. 143] was issued early last summer. This publication contains almost a thousand pages, with detailed descriptions of the most modern methods and instruments used in hydrographic surveying. In this volume are contained detailed chapters on control and signal-building, hydrography, equipment and instruments, echo-sounding, radio-acoustic-ranging, and other subjects relative to hydrographic surveying.

In the field of tides, the operation of some 50 primary tide stations was continued along the Atlantic, Gulf, and Pacific Coasts of the United States. These observations of tide still indicate a rising sea-level, which for the past two decades has been at the rate of about one-tenth foot per decade. At the same time observations of tide at certain points in Southeast Alaska indicate a falling sea-level, which obviously must be interpreted as an emergence of the coast locally. Observations indicate that in the Skagway Area this emergence is of the order of two feet during the period 1908 to date.

The operation of 12 tide stations in Central and South America was continued during the year. These are furnishing not only accurate values of the local tidal constants, but are also laying the foundation for determining the slow secular changes in sea-level. Systematic observations of tide were also begun in Greenland and short series of observations were secured at a number of isolated places in the Pacific Ocean, made possible by the presence there of our armed forces.

Only passing mention can be made of a great amount of tidal investigations and predictions carried out for the Armed Forces in connection with landings and invasions of enemy-held coasts, both in Europe and in the Pacific. Part of this is being incorporated in the Tide Tables, which now carry daily predictions for 140 of the principal ports of the world.

In recent years we had been securing daily readings of temperature and density of the sea-water at some of our tide stations. This is now being expanded to cover all the primary tide-stations in the United States and to the cooperative tide-stations abroad. These will furnish valuable data in connection with various oceanographic problems. On the west coast of South America, for example, it should throw light on the problem of the occasional incursions of the El Niño Current which bring about such wide-spread effects.

For our own coasts the data for temperature and density are now available in published form. And in this connection attention is directed to an article based on these data which appeared recently in Science entitled "Summer upwelling--Northeast Coast of Florida."

Mention perhaps should also be made of developmental work on an apparatus for recording secondary oscillations evidenced in records of tide. This instrument gives promise of wide usefulness in wave-measurements in general.

While in the past year our work in oceanography has been limited because of the pressure of war work, the war itself has brought out most forcibly the need for wider oceanographic research. It is my hope that funds will be made available after the war to permit intensified work in this promising field.

U. S. Coast and Geodetic Survey,
Washington 25, D. C.

(Manuscript received May 17, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until March 1, 1946.)

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

(See also pp. 322 and 323)

REVIEWS AND ABSTRACTS

M. KING HUBBERT: Some physical considerations bearing upon the theory of isostasy. Geophysics, v. 10, p. 455, 1945.

While the theory of isostasy, as a generality, has by now gained practically universal acceptance among the students of the earth, there is as yet no comparable agreement as to the significance of isostasy in various geological processes, and of what phenomena may or may not be ascribed to isostasy as a cause.

The purpose of this paper is to review some of the physical aspects of the isostasy problems and to deduce criteria for distinguishing between those phenomena which are manifestations of isostasy and others which are not. These criteria will be in part mechanical, and in part thermodynamical. By this means it is shown that diastrophism (including volcanism) and erosion are the truly fundamental dynamical processes of the earth, in comparison with which isostasy is but a minor and secondary adjustment phenomenon.

Geophysics

JACK W. PETERS and ALBERT F. DUGAN: Gravity and magnetic investigations at the Grand Saline Salt Dome, Van Zandt County, Texas. Geophysics, v. 10, pp. 376-393, 1945.

During May 1944, detailed gravity and magnetic surveys were made at the Grand Saline Salt Dome to secure additional information on the physical properties of this typical east Texas salt dome. The results of the surface gravity and magnetic surveys, and the subsurface gravity survey in the Morton Salt Mine are illustrated and discussed.

Densities and the available subsurface data were compiled and were utilized in a quantitative evaluation of the observed gravity data. The theoretical mass distribution which was determined by this quantitative evaluation is not intended to represent the unique solution of the geophysical and geological data; instead, it is offered as a possible solution based on relatively simple assumptions.

Geophysics

R. MAURICE TRIPP: Measurement of soil-air ions over the Fort Collins Anticline. Geophysics, v. 10, pp. 238-247, 1945.

The soil solution is examined for compounds of very low solubility product which might exist in a state of saturation over a large area; some radioactive compounds are found to fill this requirement better than any others. It is postulated that these minerals are preferentially precipitated in the interstices of the near surface soil by the evaporation of the soil water caused by the passage of gaseous hydrocarbons escaping from their subsurface reservoir. Measurements of the rate of formation of ions in the soil air over a producing structure are presented.

R. MAURICE TRIPP

Transactions, American Geophysical Union Volume 26, Number II October, 1945

THE OCEANOGRAPHIC ACTIVITIES OF THE HYDROGRAPHIC OFFICE DURING JUNE 1, 1944, TO MAY 31, 1945

G. S. Bryan

The past year witnessed the defeat of one of the greatest military powers of all times. While the feats of arms performed by our forces have been spectacular, the science of Oceanography has been behind the scenes paving the way for the invasions, helping to solve the problem of the U-Boats, and contributing to the success of many of the weapons developed during the struggle. Naturally the Hydrographic Office, which is the activity charged with the correlation of oceanographic information for the Navy, has had a prominent part in providing oceanographic data that have contributed to the final victory.

The work of our Oceanographic Unit has been outstanding, and I wish to pay particular tribute to ROGER REVELLE and MARY SEARS who are in charge of that unit in the Hydrographic Office. While for reasons of security, its reports cannot be made public at this time, I am at liberty to state that they cover, among other subjects, tides and currents, sea and swell, sea-water characteristics, bottom sediments, and biological factors. Working closely with us in the supply and analysis of information now being furnished to our fighting forces by this office, are the scientific staffs of the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution. While the primary object of all these studies is the successful conclusion of the war, a vast reservoir of data is being accumulated and analyzed, and conclusions reached that will be of immeasurable value to scientists after the war. As I stated last year, it is my intention to retain the Oceanographic Unit as a permanent component of the Hydrographic Office. Its duties will be to continue the valuable liaison now existing with various Oceanographic Institutions, to make the Office a central repository for oceanographic information, and to publish oceanographic information of service to the United States Navy, the Merchant Marine, and the scientific world.

One of the by-products of the work of the Oceanographic Unit has been the compilation of a file bibliography of oceanography. No comprehensive bibliography covering all phases of oceanography is in existence at the present time. The material on this subject is scattered throughout the literature of all the physical and biological sciences and in many languages. At the present time our file contains over 15,000 entries covering the theoretical phases of oceanography as well as the oceanography of various areas arranged by subjects. For the western Pacific, north Atlantic, and Arctic oceans, our file is as complete as New York and Washington libraries permit. However, some work is still necessary to make our coverage of the Indian, south Pacific, and south Atlantic oceans as comprehensive.

Strangely enough, the references which have proved most difficult to check have been those referring to special publications containing oceanographic information of foreign hydrographic and marine departments, especially Netherlands, Russian, and Japanese, as many of these have not been listed in well-known catalogues. We will, therefore, need access to the archives in these countries before we can rest assured that our files are complete. It is my intention, at the close of hostilities, to have this file published as a contribution of this office to the field of Oceanography.

Another contribution, which will be forthcoming from the Hydrographic Office in the near future, will be a book on waves, which is being prepared for us by HENRY B. BIGELOW. There has long been a need for such a volume that will describe to the mariner in non-scientific terms, the nature of this powerful natural phenomenon on which he sails. The book will discuss: Genesis, development, velocity, and force of waves; measurements; the transition of waves into swells; the cause and character of surf; and the effect of waves on beaches.

The book will supplement the atlases of sea and swell charts which have been prepared since the war began. The favorable progress of the war now makes it possible for me to lift the restrictions on those atlases referring to the Atlantic Ocean, and copies are now available for inspection.

The removal of restrictions in the Atlantic also makes it possible to permit inspection of our preliminary ocean current charts covering the North Atlantic, Central American waters, and the south Atlantic Ocean. It is planned to issue these charts in atlas form after the war, with the addition of 5° current roses showing the stability of the current.

During the coming year, the Hydrographic Office will complete and publish its Ice atlas of the Northern Hemisphere. The original research and work of compilation were undertaken by the American Geographical Society of New York, at the request and under the sponsorship of the State Department in 1942. About 18 months later, the work was transferred to the Hydrographic Office. The compilation of approximately 80 charts showing ice in relation to navigation has been completed and the accompanying textual and tabular material is now being assembled. The emphasis of the investigation has been laid on the navigability of the ice rather than on its generic types.

Analysis of distribution of icebergs has been included where appropriate. The atlas, which will contain about 100 pages, with a size of format of 24 by 24 inches, will include the following series of charts:

(1) Twelve monthly charts of sea-ice, covering the entire Northern Hemisphere.
(2) Three isopleth charts of the Northern Hemisphere showing river-ice conditions: (a) Average dates of opening; (b) average dates of closing; and (c) average annual number of days closed.
(3) Five monthly charts (April through August), showing the extreme maximum and minimum limits of sea-ice in the region from Hudson Bay eastward to Cape Chelyuskin in Siberia.
(4) Two series of 12 monthly charts each, showing sea-ice and iceberg conditions over the Grand Banks Region.
(5) Eleven monthly charts showing sea-ice conditions in the Sea of Okhotsk Region.
(6) Nine monthly charts showing sea-ice conditions in the Baltic Sea.
(7) Nine monthly charts showing sea-ice conditions in the White Sea.
(8) Six monthly charts showing sea-ice conditions in the Black Sea.

These charts will be accompanied by amplifying text and a series of tables listing ice-data covering several thousand ports and channels in regions where shipping is affected by ice. It will be further supplemented by a regionally subdivided bibliography on ice containing more than 1,600 entries.

From the foregoing one will gather that this atlas is the most comprehensive work of its kind ever undertaken by a governmental agency and I am sure will be extremely useful to oceanographic institutions throughout the world.

Another series of publications issued by the Hydrographic Office during the past year, which should be of service to oceanographers, are our gazetteers. These gazetteers were originally begun as a wartime project in a restricted status, but are now available to the public. Each gazetteer lists all the geographic features of the area covered, giving their latitudes and longitudes. Fifteen volumes are now available covering the entire Western Pacific Area and embracing over 400,000 names.

This war has been amphibious to a far greater extent than any previous one and correspondingly the demands for surveys, charts, and oceanographic data have vastly increased. Areas of little significance in peace time become of great importance to our Fleet during war. Scientific data covering such features as sea and swell, the character of the sea bottom, and the physical properties of the sea-water itself assume an importance entirely new to warfare. As the responsibility for conducting surveys and constructing charts, as well as for providing our Fleet with data on beach-conditions, tides, currents, and related data, rests entirely on the Hydrographic Office, the magnitude of our task can be easily visualized. It is only through the cooperation of the oceanographic societies that we have been able to accomplish this.

While military necessity forbids my disclosing any details as to actual surveying operations now underway, I can assure you that they are not dull, for the survey-ship is always in the front line. One of our vessels was at Pearl Harbor at the time of the Japanese attack. It brought down a Japanese bomber and later dragged the harbor and located one of the Japanese midget submarines which was brought up intact. At Kwajalein, a survey-party landed before the Marines. This party furnished important data used in the invasion of that island. At Tarawa, the survey party followed the Marines ashore and the island was bombed nightly for 26 of the 30 days that the survey was being conducted. Being under fire is no new experience to the survey ships of the Hydrographic Office.

In spite of all these hazards, the survey-vessels are doing a splendid job, producing on the spot field-charts for local operations and furnishing this office with detailed information for incorporation on permanent charts. The needs of the Fleet and the Merchant Marine continue to increase and the production of all types of charts for the fiscal year ending in June, 1945, will be approximately 45,000,000 copies.

The complex problem of keeping our charts up-to-date is exemplified by the recent discovery of a new islet off the northwestern coast of Colombia, near the Gulf of Darien, off Point Sabanilla. The complete coast-line of this area was surveyed by the Hydrographic Office in 1938. Upon receipt of the report from the government of Colombia of this islet, named Carabobo in honor of the vessel that discovered it, an investigation was made and it was found that the islet had sunk several feet below the surface,and that another islet had appeared farther inshore. Further investigation is underway. This area of subterranean activity should be of great interest to the seismologist, volcanologist, and oceanographer.

While everything that I have been able to tell you with regard to the oceanographic activities of the Hydrographic Office has been general in nature, many of you know of the specific projects we are engaged in and of their contribution towards victory. I wish to express my gratitude to those bodies affiliated with the American Geophysical Union who are assisting this office in its program. Together we are helping to hasten the day of victory when, no longer hampered by the exigencies of war, we may go forward on a broad program of oceanographic research that will benefit all mankind.

Hydrographic Office,
Navy Department,
Washington 25, D. C.

(Manuscript received May 30, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until March 1, 1946.)

DISCUSSION

H. W. FITCH (Mine Warfare Section, United States Navy, Washington, D. C., August 4, 1945)--It may be added that the Navy has also engaged in extensive physical, chemical, and biological oceanographic work with reference to mine warfare. This program, in which the Woods Hole Oceanographic Institution is also cooperating, is being carried on by CHARLES J. FISH, C. E. MORITZ, and associates for the Chief of Naval Operations and the Bureau of Ordnance. The nature of the work cannot be revealed at this time for reasons of security.

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

(See also pp. 318 and 323)

REVIEWS AND ABSTRACTS

Symposium: El Parícutin, Estado de Michoacán. Universidad Nacional de México, Instituto de Geología, Estudios Vulcanológicos. xiv + 155 pp., 5 figs., 14 pls., 24 photomicrographs, 60 photographs, 1945. (In Spanish.) (By TEODORO FLORES, Acting Director of the Institute; LUIS FLORES COVARRUBIAS, Chief of the Office of Geophysics and Seismology; L. C. GRATON; W. F. FOSHAG; P. D. TRASK; EDUARDO SCHMITTER; and J. HERNÁNDEZ VELASCO.)

This handsome quarto volume covers the first year of the volcano's life, from February 20, 1943, to February 20, 1944, the period to the end of July being covered in more detail than the rest of the year.

The first paper, by Teodoro Flores, gives an interesting summary of the eruptions during the first two weeks and the seismic activity immediately preceding the volcanic outbreak. Flores estimated that 13,100,000 cu m or about 34,000,000 metric tons of lava had been poured out by March 6, in about 12 days.

The second paper, "Calculations for the determination of the height of the volcanic cone," by Covarrubias, will be passed over by most geologists, but his next chapter--"Geophysical-seismological investigation of the volcanic phenomenon"--describes seismograms and calculations of the energy involved. During the time of his observations, between March 5 and 9, Covarrubias found no correlation, either in rhythm or phase, between earthquakes and eruptions in the crater, and he concluded, furthermore, that the focus of seismic impulses was in the throat of the volcano, 40 to 50 m above the surrounding plain. He postulates an oscillatory increase and decrease in magmatic pressure within the volcano acting against the inertia of the lava in the bocas to account for the character of the eruptions. In a third paper--"Interpretation of the volcanic phenomenon in the light of seismology"--Covarrubias concludes that the seismic activity registered by the Mexican Seismological Network, from the Pacific Ocean as well as from Michoacan, was more orogenic than epeirogenic, and was distinct from the temblors felt in the vicinity of the volcano. He believes the deep-seated movements to be related to isostatic adjustment between the continent and the Pacific Ocean basin.

The paper "Certain genetic aspects of Parícutin, the new volcano in Michoacan" by L. C. Graton, contains, in addition to the discussion published on pages 249 to 254 of this number of the Transactions, some considerations on the problems of volcanic heat and conduction.

Foshag very briefly summarizes the main features of the fumarolic activity. The higher-temperature fumaroles along the east and northeast fronts of the March flows were alkaline in reaction, whereas lower-temperature fumaroles along the western and northwestern fronts of the same flow were acid.

Trask gives a graphic description of the first appearance and early eruptions of the volcano, with figures on the rate of growth of the cone and outpouring of lava.

The petrography of the lavas and pyroclastics is described in some detail by Eduardo Schmitter, Chief Petrographer of the Institute, with numerous photomicrographs and four analyses. The lavas appear to be characteristic olivine basalts of the Pacific Province. The ash-fall in Mexico City from March to July was studied by J. A. Hernández Velasco; he recorded a maximum fall of 288 mg of ash per sq m during a 48-hour period ending on April 12.

The growth of the cone and the history of the lava flows during the first year are summarized in an appendix, which includes sixty photographs. Although the photographs are somewhat disappointing because of their small size and the coarse screen used in reproduction, they furnish a good background for the rest of the volume.

The Instituto de Geología is to be congratulated on the publication of the volume so promptly, particularly in view of war-time restrictions. It is most sincerely hoped that the spirit of International cooperation shown in this symposium will continue in future investigations of "El Monstro."

T. P. THAYER

LETTERS TO EDITOR

FLOW IN THE JORDAN RIVER

Reference is made to Part III, discussion by C. S. Jarvis of the paper by Karl F. Keeler entitled "Some uses and deficiencies of climatological data [Trans. Amer. Geophys. Union, Part III, p. 435, 1944]. Under the first item on this discussion, I find some data on the flow of the Jordan River at its mouth which appear to differ considerably from the actual figures. In order to illustrate this, the following information is given showing the respective data for the discharge at Allenby Bridge. The gaging station was established in 1932. The site is about seven miles upstream from the mouth, as the crow flies. There is no great difference between the flow there and at the mouth.

Drainage-area, 6,310 square miles
Average precipitation, 16.9 inches per year from 1933-43 and 17.9 inches per year from 1901-30
Average runoff, 2.4 inches per year or 1,315 cfs from 1933-43
Runoff-factor (2.4/16.9) = 14.2 per cent from 1933-43

M. GOLDSCHMIDT,
Irrigation Research Officer

c/o Water Commissioner,
P.O. Box 189,
Jerusalem, Palestine, August 10, 1945

METEOROLOGY IN BELGIUM

In Belgium we are in complete ignorance of what America has done during the war in the field of meteorology.

From time to time I receive a visit from a meteorological officer of the American Army, a guest whose amiableness I appreciate. Thus, I hear mentioned a new American journal, and progress made, particularly on the domain of the technique of radio-sounding, etc. In short, I am undergoing the torment of Tantalus! Therefore, I would be extremely grateful if you could give me some precise information.

I take the liberty of sending you some reprints of scientific papers on work carried out during the war which the Institute has been distributing only since the liberation. [Most of these are listed under Bibliography of Meteorology in this issue of the Transactions.--Editor]

JACQUES VAN MIEGHEM,
Chief, Service of Synoptic
Meteorology and Aerology

Institut Royal Météorologie de Belgique,
Uccle 3, Belgium, August 6, 1945

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

(See also pp. 318 and 322)

REVIEWS AND ABSTRACTS

C. H. DRESBACH: Organization of geophysical parties for foreign exploration. Geophysics, v. 10, pp. 137-159, 1945.

Current and future requirements of petroleum have produced a strong demand for American personnel, equipment, and techniques to be employed in the world-wide search for oil. Different, and sometimes much more difficult, conditions are frequently encountered from those customarily met in the exploration for oil in the United States. A brief consideration of some of these factors is the purpose of this paper. It is concluded that while careful preliminary planning and the design of equipment in the light of accurate information on conditions to be encountered are highly vital factors, the demonstrated and trustworthy character of the personnel conducting the operations is the biggest guarantee of success in the undertaking.

C. H. DRESBACH

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L. C. GRATON, Ciertos aspectos genéticos del Parícutin, nuevo volcán de Michoacán, El Parícutin, Inst. Geol., Univ. Nacional Mexico, pp. 61-91, 1945.

RICHARD MERRIAM, Magmatic differentiation in gabbro sills near Ashland, Oregon, Amer. J. Sci., v. 243, pp. 456-465, 1945. [Two gabbro sills, about 140 feet thick, show progressive vertical changes of mineral composition to dioritic facies which are construed as evidence of differentiation in situ by crystal settling and possibly by gas transfer.]

EDUARDO SCHMITTER, Estudio petrográfico de lavas y productos piroclásticos; determinación de las formas cristalinas e indices de refracción de algunos de las sublimados del volcán, El Parícutin, Inst. Geol., Univ. Nacional Mexico, pp. 113-131, 1945.

PARKER D. TRASK, El volcán Mexicano Parícutin, El Parícutin, Inst. Geol., Univ. Nacional Mexico, pp. 103-109, 1945.

J. A. HERNANDEZ VELASCO, Análisis de lavas, arenas, cenizas, sublimados y gases, procedentes del volcán, practicados en las laboratorios del Instituto, El Parícutin, Inst. Geol., Univ. Nacional Mexico, pp. 135-137, 1945.

J. A. HERNANDEZ VELASCO, Estudio de las cenizas del volcán caídas en las ciudad de Mexico, El Parícutin, Inst. Geol., Univ. Nacional Mexico, pp. 139-145, 1945.

C. H. WHITE, The abyssal versus the magmatic theory of ore genesis, Econ. Geol., v. 40, pp. 336-344, 1945. [Author argues that differentiation in a fluid earth would have segregated silicates and metals in widely separated layers, and that the relation between ore deposits and intrusives is structural rather than genetic.]

UNION, SECTION, AND COMMITTEE ACTIVITIES

UNION ACTIVITIES

Notice regarding the Transactions--The second-class mailing privilege has recently been granted to the Union for the mailing of the Transactions. This results in a substantial saving to the Union in the matter of postage and at the same time should make for more prompt delivery.

The granting of this privilege has caused slight changes in the appearance of this issue, as compared with the one issued in August 1945, to conform to postal regulations. The name now appears at the top of the cover page, with the only reference on this page to the National Research Council appearing at the bottom. Further, because of the terminology used by the Post Office Department with reference to second-class matter, our successive issues have become "Numbers" instead of "Parts."

The Editorial and Publication Committee solicits your constructive comment with regard to each issue, both as to its make-up and content. Please send in also notes and personalia of interest to the membership.

It is further requested that changes of address be furnished promptly. The Transactions are now issued bimonthly in the even-numbered months (February, April, etc.), and receipt of change of address by the first day of the month of issue will facilitate prompt delivery and at the same time minimize the work of the Office of the Union in processing returned copies.

Notice regarding Directory--It had been the plan to issue a new Directory of the Union during the late summer or fall. The changes of address have been numerous during the entire war-period, but now with the ending of the war even a greater number of changes is anticipated. Please send in changes of address as early as possible and an attempt will be made to prepare an up-to-date Directory of the membership early in 1946. You can facilitate this by forwarding changes of address promptly.

SECTION ACTIVITIES

Section of Meteorology

ADDENDUM: Minutes of the Annual Meeting of 1945, Section of Meteorology, American Geophysical Union (Trans. Amer. Geophys. Union, v. 26, Pt. I, pp. 154-155)

At the afternoon session of the Annual Meeting on May 31, 1945, President Reichelderfer and G. D. Cartwright, President of the District Branch of the American Meteorological Society, presided, as this was a joint session with the latter organization.

H. D. HARRADON, Secretary

COMMITTEE ACTIVITIES

Special Committee to Study the Affiliation of the American Geophysical Union with the Proposed American Geological Institute

There is to be an informal assembly of the representatives of the thirteen principal societies that are serving the field of Earth sciences in Washington October 12 and 13, 1945, called jointly by the Division of Geology and Geography of the National Research Council and the Geological Society of America. The purpose of this meeting is to effect the organization of the "coordinating committee" [see Trans. Amer. Geophys. Union, v. 26, Pt. I, p. 169, 1945] that will serve as a pilot organization to explore the objectives of the proposed American Geological Institute and the ways and means of attaining them. W. T. Thom, Jr., Chairman of the Union's Special Committee on this matter, will act as the representative of the Union.

Report of Committee on Audit for Fiscal Year, July 1, 1944, to June 30, 1945

A. G. McNish (Chairman), R. H. Weightman

Your Standing Committee on Audit has examined the financial statement of the General Secretary for the fiscal year ended June 30, 1945, and found it in agreement with the financial records of the American Geophysical Union. Receipts for the year including a cash balance on hand on July 1, 1944, of $12,499.52 were $29,986.83. Total disbursements for the year were $21,121.94, leaving a balance as of June 30, 1945, of $8,864.89, this balance being in agreement with a statement from the Riggs National Bank of June 30, 1945, of $11,132.92 from which must be deducted $2,268.03 for checks outstanding. Accounts receivable are reported as $2,211.70 and accounts payable as $157.80.

Financial Statement, Fiscal Year, July 1, 1944, to June 30, 1945

Receipts		
Cash balance, July 1, 1944, as reported from June 30, 1944		$12,499.52
American Geophysical Union	$12,323.92	
William Bowie Medal Fund	175.60	
Dues, 1942-1946		7,316.33
1942	$ 36.00	
1943	111.00	
1944	920.96	
1945	6,202.50	
1946 et seq.	45.87	
Sales of Publications		3,384.81
Transactions	$1,101.50	
Reprints	2,233.68	
Bibliography of Hydrology	14.38	
List of Members and Officers	1.90	
Exhibit Maps	32.35	
Washington Assembly	1.00	
Special Fund and Miscellaneous Contributions		154.13
National Research Council Account Grants 1944 and 1945		632.04
Rockefeller Foundation Account Grant 1945		6,000.00
Total receipts ($12,499.52 + $17,487.31)		$29,986.83
Disbursements		
Transactions of 1944		$ 5,539.81[a]
Reprints		2,217.86
Expenses, General Secretary's Office		11,904.73
Services	$9,648.25	
Equipment	373.27	
Stationery	830.61	
Postage	1,052.60	
Committees		1,028.59
Executive	$ 55.28	
Membership	189.70	
Statutes and By-Laws	47.04	
Editorial and Publication	686.50	
National Welfare and Related Functions	9.25	
Precise Surveys and Maps	6.50	
American Geological Institute	34.32	
Sections		29.35
Seismology	$ 12.18	
Hydrology (Los Angeles Regional Meeting)	17.17	
25th Annual Meeting (1944)		174.22
26th Annual Meeting (1945)		210.88
William Bowie Medal		16.50
Total disbursements		$21,121.94
Balance June 30, 1945		$ 8,864.89

[a] This consists of items for publication of 1,066 pages of *Transactions* of 1944: (1) Services in preparing master-copy, $765.16; (2) photographic and drafting services, $473.84; (3) planographer for paper, binding, and printing, $4,300.81.

Riggs National Bank per statement of June 30, 1945				**$11,132.92**
Less checks outstanding:				
No. 1547	**$ 8.00**	**No. 1567**	**$ 64.30**	
1549	**36.65**	**1568**	**5.00**	
1551	**1.25**	**1569**	**11.25**	
1555	**9.24**	**1571**	**425.90**	
1556	**832.31**	**1572**	**10.50**	
1557	**6.00**	**1573**	**75.00**	
1558	**5.40**	**1574**	**75.00**	
1559	**9.59**	**1575**	**75.00**	
1560	**10.29**	**1576**	**75.00**	
1561	**9.45**	**1577**	**75.00**	
1562	**55.95**	**1578**	**75.00**	
1563	**11.87**	**1579**	**75.00**	
1564	**19.98**	**1580**	**75.00**	
1565	**60.10**	**1581**	**75.00**	
			Total checks outstanding	**2,268.03**
			Balance June 30, 1945, as above	**$ 8,864.89**

Distribution of balance

American Geophysical Union	**$ 8,705.79**[b]	
William Bowie Medal Fund	**159.10**	
		$ 8,864.89

Bills receivable		
Publications		**$ 664.57**
Transactions	**$ 159.98**	
Reprints	**500.04**	
Miscellaneous	**4.55**	
Dues		**1,547.13**
Seven Members in former enemy countries, postponed	**$ 96.00**	
Six Members, 1942, 1943, 1944, 1945	**72.00**	
Thirteen Members, 1943, 1944, 1945	**115.00**[c]	
Sixty-one Members, 1944, 1945	**366.00**	
Three hundred fifteen Members, 1945	**944.00**[d]	
Total gross bills receivable	**$1,593.00**	
Deduct dues paid in advance	**45.87**	
Total net bills receivable		**$ 2,211.70**

Bills payable		
Telephone, June service	**$ 6.04**	
Stationery	**7.17**	
Section of Seismology	**3.66**	
Section of Geodesy	**4.53**	
Reprints paid in advance	**136.40**	
Total bills payable		**$ 157.80**

Recapitulation

	A.G.U.	**Bowie Medal Fund**	**Total**
Cash balances	**$ 8,705.79**	**$159.10**	**$ 8,864.89**
Bills receivable	**2,211.70**	**0.00**	**2,211.70**
Totals	**$10,917.49**	**$159.10**	**$11,076.59**
Bills payable	**157.80**	**0.00**	**157.80**
Net balances	**$10,759.69**	**$159.10**	**$10,918.79**[e]

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[b] **Of this, $3,340 (one-third of Special Fund of $10,000 contributed by Members and friends) is to be held for expenditure subsequent to June 30, 1946.**

[c] **One Member owes but $1 for 1943.**

[d] **One Member owes but $2 for 1945.**

[e] **There is available also for the fiscal year ending June 30, 1946: (1) Grant by National Research Council, $400, and (2) account request against grant by Rockefeller Foundation, $7,000 (leaving a balance in the grant for the year ending June 30, 1947, of $7,000).**

Cost of equipment owned by American Geophysical Union

One 18-inch large primer Burroughs typewriter, serial No. 60A232450	$190.80
One 10-inch elite Royal typewriter, serial No. KHM-2076351	100.31
Two 4-drawer, 5x8-inch steel filing cases (gift)	0.00
Two steel posture chairs	22.00
One Globe-Wernicke, 2-pedestal, flat-top steel desk, A.G.U. No. 1, 60x34 inches	49.18
One Triner postal scale, 4 lbs. by 1/2 oz.	16.20
One Arrow stapler	6.75
One walnut flat-top desk, A.G.U. No. 2, 34x66 inches, with glass top	95.43
One walnut typewriter desk, A.G.U. No. 3, 34x60 inches, with glass top	100.72
One walnut typewriter desk, A.G.U. No. 4, 34x60 inches, with glass top	89.72
One walnut chair	21.50
One costumer, walnut finish	3.50
Ten desk trays, walnut finish	14.00
One 15-inch Eastman trimmer	13.50
Twelve copies, Manual of Style, University of Chicago Press	32.50
Total cost of equipment	$756.11

[Note: The Union has a large stock of Transactions of past years available for sale, but these are carried as without value in the inventory.]

Transactions, American Geophysical Union Volume 26, Number II October, 1945

ANNUAL LETTER OF THE PRESIDENT OF THE SECTION OF HYDROLOGY TO THE MEMBERSHIP, September 1, 1945

The Annual Letter with its review of progress and chart of trends may not now be so essential since the establishment of the Transactions as a bimonthly with news notes and viewpoints in addition to the articles. Furthermore, since the Union is becoming closer knit, an annual letter from the President or Secretary of the Union may be more appropriate than from the executives of the Sections. This development must be the next step of the future.

Revised Statutes and By-Laws--The ideal toward which the revised Statutes and By-Laws, as of July 31, 1945, is tending is the placing of the Union within the members rather than apart in Washington, D. C. or at regional centers. Therefore, hereafter elections of officers of both Union and Sections will be held by letter-ballot of the entire membership rather than by only those who attend the Annual Meetings.

In addition, papers can be submitted by absent members for presentation on the program of the Sessions or for publication directly in the Transactions.

Still better, Regional Branches have now been authorized for the entire Union. A Branch is being established in the Tennessee Valley and a Regional Meeting in New England has been planned by Drs. FIELD AND STETSON.

Provision has been made for awards and medals and intersociety representation--the latter originated by the Section of Hydrology.

The Executive Committee of the Union has been placed on a broader base of representation and continuity by including secretaries of Sections and immediate past-presidents of the Union and the Sections.

The increase of annual dues to $5.00 in January 1946, aided by the steady growth in membership, should increase the vitality of the Union proportionately.

The Annual Meeting

Attendance--The Annual Meeting of the Union approached its former high in attendance despite the restriction that not more than 50 could be in special attendance from outside Washington, D. C. The total of 485 was made possible by the large number of scientists resident in Washington and those who chanced to be there on national and war service.

Program--The program of the Section of Hydrology, prepared under the supervision of Chairman HERTZLER, who attended the sessions, represented a distinct effort to present appealing topics, alert discussions, and a comprehensive round table on leading subjects.

Round tables

Characteristics of hydrologic regions--The round table on Characteristics of hydrologic regions, carried over last year, because of the public address of Major RAINIER on Water for MONTGOMERY in Africa, became a memorial to Chairman ROBERT E. HORTON, who died on the eve of the meeting and who had already seen the necessity of continuing the study for another year.

The project will be carried on by Dr. THORNTHWAITE with a broad committee covering precipitation, evaporation and transpiration, and surface- and ground-water. EDWARD N. MUNNS of the Forest Service has suggested that "all fields should be adequately covered and that these fields should include at least climatology, geology, soils, and runoff."

Land-erosion--The subject of land-erosion will now be studied intensively and broadly under the leadership of Dr. LOWDERMILK and a committee of specialists.

In cooperation with Dr. RICHARD E. FULLER, directing the broad study of the evolution of Parícutin Volcano for the National Research Council, the Committee is considering the study of the spectacular erosional phenomenon on Parícutin as its first major project. Dr. LOWDERMILK left for Mexico in August and hopes to make this a continuous and joint project with the Mexican government. "As you know," he writes, "Dr. REED BAILEY is joining me in this study because of his experience in mud-flows."

The Research Committee on the Dynamics of Streams under Dr. STRAUB will continue its special studies, which will be fitted into the broader program of land-erosion.

Ultimately, reference-books on both hydrologic regions and land-erosion should develop from the studies.

Other Research Committees--Despite the inroads of war on the free time of the chairmen and members of the Research Committees, the reports for 1943-44 represent increased breadth and detail. The reports for 1944-45 will contain the work also of sub-committees seeking greater specialization. Since the war has now ceased, an abundance of research bearing on strategic problems will probably be released for publication. The best is therefore just ahead.

Citations and awards--Your President received from Chairman MUSGRAVE the following letter and report of the Committee on Awards, dated April 23, 1945, which was approved by the Union.

"You may have learned already that Dr. R. E. HORTON died suddenly yesterday. I understand that he had just returned from a trip to Oklahoma, was extremely tired, and that apparently the heart simply stopped beating.

"Only this morning I had made arrangements for submitting a final report of the Committee on Awards, this report merely awaiting final concurrence and approval on the part of Dr. HORTON. In so far as we know, this report does have in it all of the major ideas of Dr. HORTON, and in so far as we know, it has nothing in it to which he would object. As it stands, the report definitely represents a unanimous opinion on the part of the majority of the Committee, and I am, therefore, enclosing a copy of it herewith."

REPORT OF COMMITTEE ON AWARDS TO THE EXECUTIVE COMMITTEE, SECTION OF HYDROLOGY, AMERICAN GEOPHYSICAL UNION

G. W. Musgrave, Chairman
N. C. Grover R. E. Horton

The Committee on Awards recommends that the Section of Hydrology establish awards for especially meritorious scientific papers in order: (1) To stimulate research in hydrology; (2) to encourage younger men who are engaged in hydrologic work to do independent and original thinking, and (3) to secure for the Transactions the best possible papers that contribute directly to the advancement of hydrologic science.

It is proposed that these awards be inaugurated on the basis of two awards as follows: (1) An award for the best first paper upon presentation to the American Geophysical Union by a scientist who shall have received his baccalaureate degree within not to exceed ten years prior to submission of the paper or report; and (2) an award for the paper which makes the greatest contribution to the advancement of scientific hydrology, this award to be open to any author of a paper presented for publication by the Union.

It is further recommended that the awards be made by the Executive Committee of the Section of Hydrology, which shall set up such standards and criteria as that Committee deems suitable, and that the awards be made annually if papers of sufficient quality have been presented for publication, or less frequently if in any given year the papers that have been presented are not especially meritorious.

In accord with the arrangements made by the President of the Section of Hydrology with the Executive Committee of the Union "neither money nor medals would be given" although "later something more distinguished than a letter or parchment can be tried." It is therefore recommended that a parchment similar in general form to that now given honorary corresponding members be provided by the Executive Committee of the Section.

The announcement of citations and awards will be initiated at the Annual Meeting of 1946 and be based by the Executive Committee on the excellence of papers of the previous year.

ROBERT E. HORTON Estate--The American Meteorological Society and the American Geophysical Union are fortunate in having won the confidence of ROBERT E. HORTON, whose sole ambition was to seek the scientific truth underlying every engineering problem brought to him by his consultants. Though his income from consultation was spent freely in research, it grew steadily because of his greater efficiency. At equal pace grew his files of problems with accumulated data and suggested solutions.

This collection has been left in his will as a reference and source library to the American Geophysical Union, together with 70 per cent of his residuary estate as a fund for publishing worthy papers. Ultimately approximately $175,000 should be available, but his ideals for selecting such papers should be embodied in the acceptance of the gift while they are still fresh in mind.

A letter from Dr. HORTON to the President of the Section [Trans. Amer. Geophys. Union, 1944, Part 5, p. 821, 1945] indicates that a paper should not be rejected for length or "merely because it contains some erroneous or questionable material or conclusions, provided it does contain something which represents an honest-to-goodness individual research and an advance--no matter how trivial--in the science of hydrology. It is almost a necessary incident to research-publication that no paper is ever absolutely final or perfect. Discriminating readers will, however, in general, not be greatly misled, especially if, as I have long advocated, the basic data be published in the paper so that the reader can make his own deductions and draw his own conclusions. In one respect I feel that much of the publication of the American Geophysical Union is superior to publications of some other organizations in that most of the papers published do contain original data. This is, of course, a large subject and it cannot be even satisfactorily summarized in a short letter. My own opinion is that with the publication of a journal, papers should be available for submission for publication at any time, without being presented before a meeting, and that one of the primary functions of the Editors of the Section should be to cooperate with the authors of papers, suggesting amendments and revisions which will improve the character and quality of the paper rather than rejecting the paper because of deficiencies, provided it meets the one fundamental specification that it contains something of real value."

This opportunity of publication should be shared with foreign manuscripts also, which can well bring new viewpoints but lack means of publication. Science should know no boundaries and the war has broken down even the political barriers.

Intersociety relations--The organization of the Committee on Intersociety Relations, with W. W. HORNER as Chairman, is now approaching completion. All of the eight organizations invited have most heartily accepted and all but three representatives have been chosen. The organizations are: American Society Agricultural Engineers; American Society Civil Engineers; American Meteorological Soceity; American Water Works Association; Geological Society of America; Society of American Foresters; Society of Economic Geologists; and Soil Science Society of America. This Committee is neither aggressive nor necessarily active. It is rather one of reflection and discussion of mutual problems common to the various organizations to be conducted whenever two or more members of the Committee chance to meet. This may be at the Annual Meeting of the Geophysical Union or at the meetings of any of the other organizations or at any Regional Meeting. Its purpose is to create atmosphere and understanding, which is cooperation in its highest sense.

A national achievement--The President was fortunate in being able to make a long-planned visit to the Tennessee Valley to study the possible effect of minimum quantities of snow on the spring runoff. He found erosion, poor crops, and floods almost non-existent because of the achievement of the Tennessee Valley Authority during the past 12 years. Navigation for vessels of nine-foot draft is now available from the Gulf to Knoxville. Schools and homes compare favorably with those in other states. A bill, commended by the late President ROOSEVELT, is now in Congress, to provide dams and conservation to the adjoining Cumberland River Basin.

International meetings--The Soviet Academy of Sciences deserves highest commendation for restoring international activity in science while the War was still being brought to a close. From June 15 to 30, 1945, representative scientists from many countries of the world were guests of the Academy at Moscow and Leningrad at its 220th Anniversary as it revealed Russian progress in arts and science and sought conference and cooperation from its neighbors. Approximately 135 guests were present, brought by plane and entertained at the Academy's expense.

MERRILL BERNARD and the President, representing hydrology, were in the original group of seventeen Americans at the Jubilee but Dr. REICHELDERFER, Chief of the United States Weather Bureau, and Dr. ROSSBY, Director of the Institute of Meteorology at the University of Chicago, arrived for a longer stay at its close. The trip round the world occupied 29 days, but for the actual passage, including refueling and lunch, only seven days.

It now seems probable that the long-postponed meeting of the International Union of Geodesy and Geophysics planned at Oslo, Norway, for 1942 may be held there in 1946 or 1947. The Executive Committee of that Union hopes to meet at Oxford, England, in December, 1945. The Soviet scientists have eagerly accepted an informal invitation to be present at Oslo. The success of the Soviet Academy of Sciences is both challenge and assurance.

Officers hold over till June 1, 1947--Because of the War and the lack of synchronism between the terms of office for the General Secretary and for several of the Sections, the Executive Committee of the Union postponed all elections until 1947, when a general election by letter-ballot will be held. This action has now been confirmed by the revised Statutes and By-Laws. This will mean a five-year administration for the Section of Hydrology, which will carry it through the period of return of the membership to normal peacetime activity and will give time for the new policies of the Section to mature.

The Executive and all other Committees will continue with the elected officers until the end of the term. The place on the Executive Committee left vacant by the death of Dr. HORTON has been filled by the election of STANLEY W. LOHMAN of Denver, Colorado, who will represent the near-West.

To the newly elected members of the Union and Section, the heartiest greetings are extended by all. You will increase the momentum of the Union and are invited to join its Committees. Your reports and papers will be welcomed. Unlimited horizons are before us.

Reno, Nevada,
September 1, 1945

J. E. Church, President
Section of Hydrology

To promote the study of problems concerned with
the figure and physics of the Earth, to initiate and
coordinate researches which depend upon international and national cooperation, and to provide
for their scientific discussion and publication

UNSELFISH
COOPERATION
IN RESEARCH

Transactions, American Geophysical Union Volume 26, Number III December 1945

VERTICAL CONTROL SURVEYS FOR RECONNAISSANCE MAPS

C. F. Fuechsel

(Published by permission of the Director of the Geological Survey,
United States Department of the Interior)

Abstract--Much of the previously unmapped area of the world has now been covered with high oblique aerial photography by the United States Army Air Forces. Future expeditious use of these data for the preparation of reconnaissance topographic maps requires several known elevations per hundred square miles. An economical method of developing such control is described herein.

Generally speaking, the control requirements for topographic maps descend in order directly with the publication scale and inversely with the contour interval chosen for a given map series. The plotting process to be employed and the physiographic types to be mapped are strong influencing factors, usually tempered by expedience, however, when extremely difficult and hazardous terrain is encountered by the field parties.

A very considerable range of map types is embraced in the term "reconnaissance." For the present purpose, maps of intermediate scale (four miles to the inch), suitable for general planning and development use, will be discussed. Such maps usually employ a one-hundred or two-hundred foot contour interval which affords a tolerance of twenty or thirty feet in vertical control used for photo-orientation and even greater latitude for those points controlling topographic detail only.

A brief discussion of the methods formerly employed by the Geological Survey in preparing maps of the "four-mile" scale for Alaska will be helpful in studying requirements for future mapping from the high oblique and vertical aerial photographs taken by the Army Air Forces during the past few years.

Plane-table and telescopic alidade were the topographers' principal tools while the mountain-transit, panoramic mapping camera, and aneroid barometer were employed for supplementary purposes. Horizontal control was accomplished by astronomic observations, graphic triangulation, and to a limited extent by traverse linkage. Reference to vertical datum was held principally by trigonometric leveling. Physiographic detail was added to this controlling frame partly as the work progressed in the field and later completed from the panoramic photographs during the office season.

The fact that high oblique aerial trimetrogon photography now covers a vast portion of the world's land area indicates that future mapping for general development purposes will be oriented toward the intensive use of these source data wherever they exist. Therefore field surveys will tend to be of a supplementary nature rather than of comprehensive mapping aspect.

The true orientation of aerial photographs is an absolute requisite for their effective use for mapping purposes and vertical control is the only practicable means by which a rigid orientation can be attained. A minimum of three points, but preferably several more, should be available in random distribution, for each oblique exposure. This is not a difficult objective since the oblique covers about one hundred square miles effectively for mapping purposes.

The field problem of securing several low order elevations per hundred square miles may be solved by barometric or vertical angle surveys. Special devices for determining the height of aircraft may be applied in the future to this problem, but at the present they can be regarded only as an aid in furnishing approximate terrain clearance data for very small scale aeronautical charts.

Recent experiments in developing vertical control by altimetry indicate that this approach is feasible even for relatively large scale mapping where a tolerance of only two or three feet is required [see 1, 2, 3, and 4 of "References" at end of paper]. However, the limiting factors of working radius and relatively rare weather conditions might prove a very serious handicap in attempting to apply this procedure to long-range reconnaissance surveys. Perhaps when the helicopter is practicable for everyday use, and extensive areas can be "covered" during the brief periods of proper atmospheric conditions, this method can be successfully applied.

Meanwhile, vertical angle surveys of long range appear to meet the conditions under which the majority of reconnaissance mapping projects must operate. The ability to reach out in areas of moderately rolling to rugged terrain and establish elevations over a 40 or 50 mile belt from a single well-planned field meander has great advantage in undeveloped areas where the movement of field parties is difficult and costly. Although the technical aspect of the long-range survey appears relatively simple, certain operational problems are presented in addition to arduous terrain. Identification of the many points to be observed at each station, the reading time required, and the complexity of any graphic or other means of carrying a horizontal scheme furnishing intersections to all desired points are problems requiring simplification. In order that the field maneuver may be reduced to a practicable scheme of large figures, some means must be supplied to record, and later to interpolate, readings on features extraneous to the main scheme. Unquestionably, the solution is to photograph the whole horizon from each occupied station, preferably with a panormic camera to facilitate the field operation and office analysis. The panoramic cameras formerly used to supplement field mapping operations were relatively large and heavy, covered only a third of the horizon at each setting, and are now mechanically obsolescent. A new panoramic camera has recently been designed by the United States Geological Survey for experimental purposes in connection with Alaska mapping. The new camera covers the entire horizon in one continuous exposure, is mechanically simple, and considerably smaller and lighter than the old fixed film type, though a lens of similar focal length (127 mm) is employed. (See Figs. 1 and 2.)

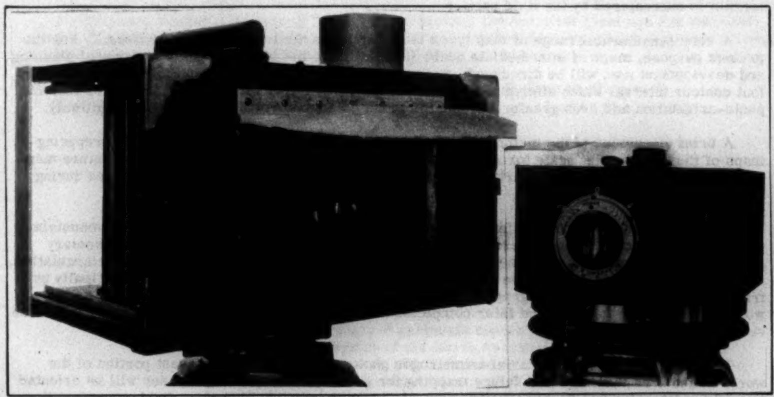

Fig. 1--Size comparison, old style panoramic camera (at left) and experimental panoramic camera of recent design with same focal-length lens

In the focal plane aperture, which is 1/10 of an inch wide, three fiducial wires have been placed. One wire, close to the lens axis, describes a reference line on the film from which readings are made with a simple comparator or Brinnel type microscope to features in the landscape which were determined in the field. Values for the several sectors of the reference line are then computed and used in determining the equivalent vertical angles of all other features for which elevations are desired. (See Fig. 3.)

The other two fiducial wires have been placed near the upper and lower extremities of the focal plane slot to furnish a reference value for detection of scale change in the film or paper prints. (See Figs. 4a and b.)

As the camera is rotated the film is driven across the focal plane slot by direct gearing to effect a passage of $2\pi f$ of film in one complete circuit of the camera. A relatively large take-up

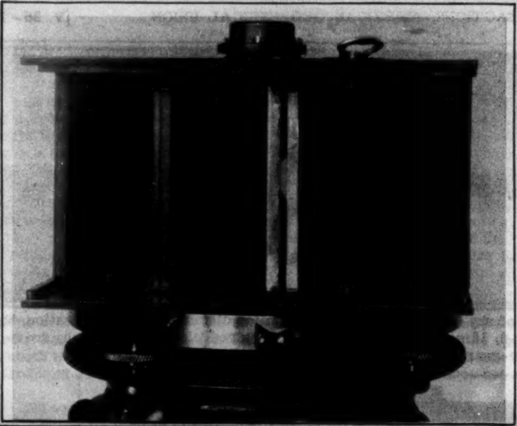

Fig. 2--View of focal plane of experimental camera

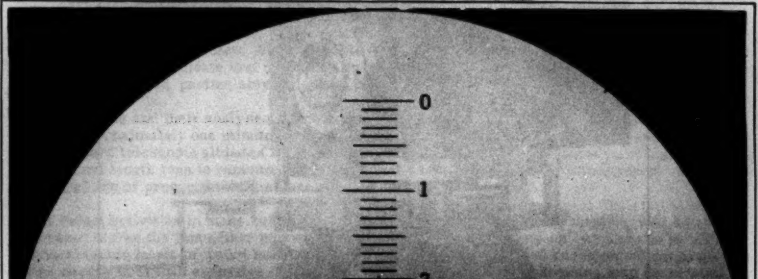

Fig. 3--View with scale for measuring vertical angles

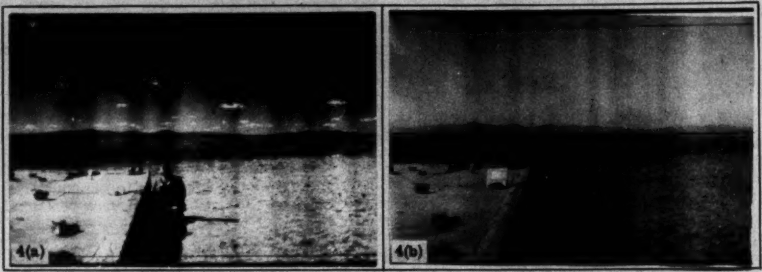

Fig. 4--Portion of exposure of sky-line panorama about 30 miles distant. (a) Manual rotation, handle through worm-gear, f-8, 15 sec. trip, red filter (A), infra red film (b) Rotation by draw-cord and worm-gear, f-8, 10 sec. trip, panchromatic film, K filter

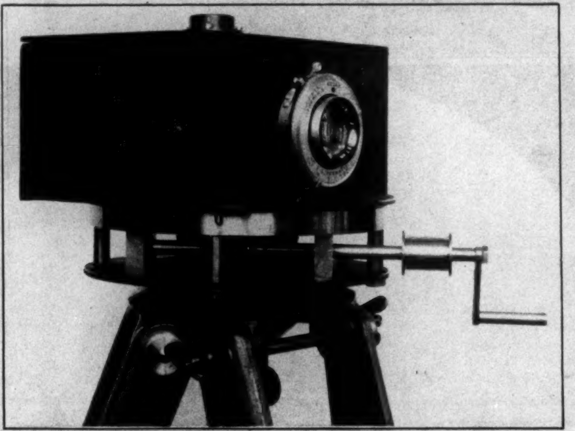

Fig. 5--Experimental model camera with spool and handle added for temporary use

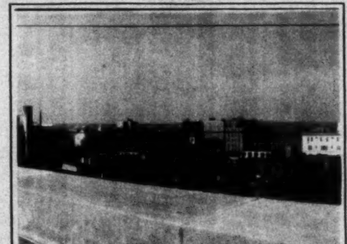

Fig. 6--Portion of exposure made with mechanical drive, f-22, 25 sec. trip, panchromatic film, no filter

drum has been employed to keep this requirement well within the one per cent tolerance, beyond which optimum definition would not be attained.

In its simplest mechanical arrangement the camera is "walked around" with a rod or rotated by a draw cord or handle through a worm and gear, as showin in Figure 5. A minimum of working parts is desirable for operations in remote areas to reduce the possibilities of breakdown and increase the chance of repair, in such event, with the limited facilities at hand. However, the "banding" due to manual rotation, which is evident in Figures 4 a and b, made with the elementary mechanism, may be somewhat objectionable if the camera is used for other purposes. Consequently an arrangement of mechanism has been designed, similar to the spring drive, gearings, and governor employed in phonographs, which will fit into the present camera box. Figure 6 is a view taken using this mechanism. Considerable improvement is evident in the elimination of banding by the mechanical drive. A slight amount is noticeable in this particular exposure, however, since the driving mechanism was held by hand and connected to the worm shaft with a piece of rubber tubing.

It is felt that practice by the operator will considerably reduce the banding evident in exposures made by manual rotation of the camera. At the present time only a few pictures have been taken, and it can therefore be expected that experience will increase the operator's ability to make a smooth transit of the horizon. However, the present specimens are not objectionable from a utility standpoint as the banding is due to exposure variations and does not affect angular values.

No serious loss of definition in the landscape feature is discernable in the "banded" prints, and a moderate amount of exposure-variation may well be an advantage in reading certain sectors of the horizon where a fixed exposure might have been either too fast or slow. Manual operation also enables the surveyor to make appropriate changes in tempo for variations of brightness in the several sectors of the horizon. Such probable advantages, in addition to greater security from mechanical failure, indicate that the manually operated design may find greater favor for the purposes just described, particularly for operations in remote regions.

Field tests and their analyses indicate that interpolation readings of vertical angles can be made to approximately one minute of arc. This is practically equivalent to field readings made with standard telescopic alidades which have one minute verniers. For surveys of higher order a longer focal length lens is recommended, but in that event, the field control instrument should have a vertical arc of proportionately higher reading value.

Present activities in many countries indicate that the total of world mapping will be greatly increased during the immediate postwar years. The general "tooling-up" appears to be along reconnaissance lines, probably because maps for general planning and development purposes are more readily sold than expensive detailed surveys in countries just becoming map conscious. The continuing improvement of reconnaissance mapping procedures is therefore of prime importance at this time, particularly those contributions supplementing trimetrogon photography which already covers over a quarter of the world's land area.

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Washington 25, D. C.

(Manuscript received May 23, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until May 1, 1946.)

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PROBLEMS IN PHOTOGRAMMETRY

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Abstract--This paper deals very briefly with the topic, "Problems in photogrammetry," not with any specific problem or solution, but rather with the generalized subject of photogrammetry problems. It is intended to show how research projects arise in the course of routine teaching of photogrammetry.

As the new Manual on photogrammetry published by the American Society of Civil Engineers suggests, certain minor controversies regarding such details as symbolism, technical terminology, etc., have arisen from time to time during the development of the theory of photogrammetry. In this connection, I wish to mention particularly the orientation of an aerial photograph in space. Any set of quantities whose values suffice to specify uniquely the spatial orientation of an aerial photograph can certainly be used as what might be called elements of spatial orientation of an aerial photograph. These quantities are usually, but not necessarily, angular; they may be linear quantities. In general, three such quantities are required, but there is no restriction to this number, provided that proper precaution is taken to avoid inconsistencies in quantities which may not be independent. Personally, I have no arbitrary ideas regarding the selection of a system of orientation elements for an aerial photograph. The only requirements, as far as I can see, are that the elements used actually specify the orientation uniquely, and that they are simple and convenient to use in connection with any particular photogrammetric processes under discussion.

If, therefore, objections are raised to my original designation of the orientation of an aerial photograph by means of three angular elements, namely, the resultant tilt, the swing or photographic direction of the tilt, and the azimuth of the principal plane or the ground or survey direction of the tilt, these objections are certainly not surprising; for there is certainly a wide variation in the photogrammetry problems requiring specification of photograph orientation. I have employed extensively the tilt-swing-azimuth method of orientation, merely because of the simplicity of its application to a geometry of the aerial photograph, which has been found powerful from the standpoint of teaching.

Recently, however, we have been developing a completely new geometry of the aerial photograph. It is based upon an entirely different method of specifying the spatial orientations of the aerial photographs, one which we call the direction-cosine method. Positions of ground-points, usually designated by X, Y, and Z coordinates, always refer to some rectangular coordinate-system established for the ground-surveying, probably in most cases to one of the modern state coordinate-systems for geodetic surveys, but at least in all cases to some system with definite X, Y, and Z axes, which we call the survey-space-coordinate-axes. Also, each individual photograph serves to define another system of space-coordinate-axes, with x and y axes coinciding with the corresponding geometric axes of the photograph as defined by the camera marks, and with a z-axis coinciding with the camera axis. The axes for this system we designate as the photographic-space-coordinate-axes. The spatial orientation of the photograph can then be specified uniquely either by the direction-cosines of the survey-space-coordinate-axes referred to the photographic-space-coordinate-axes, or by the direction-cosines of the photographic-space-coordinate-axes referred to the survey-space-coordinate-axes. Actually we have chosen the former. In this system, therefore, the orientation elements of an aerial photograph consist of nine direction-cosines, three for each axis, instead of only the three angular elements previously used, but these nine elements are not independent and in reality comprise but three independent quantities. We have introduced this new approach to the geometry of the aerial photograph for two reasons: first, the photogrammetric solution of many surveying problems is considerably simplified; second, the geometry developed lends itself to the derivation of interesting and useful relationships between center and wing-photographs in either multiple-lens photography or trimetrogon photography.

Permit me to say at this time that, with this so-called direction-cosine system of spatial orientation, the simplified solutions have already been worked out for all of the fundamental problems of photogrammetry, namely, space resection, space orientation, space intersection, special cases of intersection, photogrammetric extension of control, scale data determination, etc. A discussion of the theory of this revised geometry of the aerial photograph constitutes No. 15 in our series of bulletins on photogrammetry, which is now in press. This bulletin, however, will lack specimen computations based upon the new system, because time has not yet been available for preparing these for publication, although these computations have been tried and found satisfactory. These computations will constitute a later bulletin in the series.

The bulletin in press does show how the direction-cosine system serves to prove certain groups of simple relations between space orientation elements of center photographs and wing-photographs in either trimetrogon or multiple-lens photography. The formulas expressing these relationships are printed without proof in Appendix I at the end of the paper.

Group 7.14 of these formulas, for any single photograph, give the direction-cosines of the photographic-space-coordinate-axes, referred to the survey-space-coordinate-axes, in terms of the three orientation elements formerly used, the tilt, swing, and azimuth of the photograph. Group 7.21 give the direction-cosines of the survey-space-coordinate-axes, referred to the photographic-space-coordinate-axes, in terms of the tilt, swing, and azimuth. These latter direction-cosines are the ones which are actually defined as the elements of orientation of the aerial photograph in the direction-cosine system.

Then group 7.31, conversely, give the tilt, swing, and azimuth of the photograph in terms of the direction-cosines of the photographic-space-coordinate-axes, referred to the survey-space-coordinate-axes. Group 7.41 give the tilt, swing, and azimuth of the photograph in terms of the direction-cosines of the survey-space-coordinate-axes, referred to the photographic-space-coordinate-axes. In other words, the last group of formulas give the elements of space orientation of the photograph, as they were formerly used, in terms of the orientation elements in the direction-cosine system.

Therefore, groups 7.21 and 7.41 show that the elements of spatial orientation for any aerial photograph on the new direction-cosine system and on the old tilt-swing-azimuth system, are virtually interchangeable, since either set can easily be found from the other.

Next, there are shown several groups of formulas concerning trimetrogon photographs. The two groups under 8.13 give the direction-cosine elements of orientation of any center photograph, in terms of the direction-cosine elements of orientation of either the left or right wing-photograph, no matter what the tilt of the center photograph may be. The angle θ in these formulas is the fixed angle between the axis of the center camera and that of either wing camera, usually but not necessarily 60°. The formulas under 8.23 give the direction-cosine elements of orientation of each wing-photograph, in terms of the corresponding elements of orientation of the center photograph. By means of these two groups of simple relations, the direction-cosine elements of orientation of all three photographs in any trimetrogon group become known, if these elements are given for any single photograph in the group.

Similarly, reverting to the old tilt-swing-azimuth system of orienting an aerial photograph, the group of formulas under 8.33 gives the tilt, swing, and azimuth of the principal plane of the center photograph, in terms of similar orientation elements of either wing-photograph in a trimetrogon group. And the group of formulas under 8.43 gives, conversely, the tilt, swing, and azimuth of either wing-photograph in terms of corresponding elements of orientation of the center photograph. In these formulas, as before, θ is the fixed angle between the axis of the center camera and that of a wing-camera. (Formulas 8.35 and 8.45 are special very useful forms of the azimuth relationship between center and wing-photographs.)

These groups of formulas, therefore, collectively, serve to give the spatial orientation elements for all photographs of a trimetrogon group in both the direction-cosine system and the old tilt-swing-azimuth system, whenever there are known the orienation elements in either system of any one of the three photographs in the group.

Furthermore, in connection with these formulas for trimetrogon photographs, it is noteworthy that the tilt and swing of a center photograph can be found from the tilt and swing only of either wing-photograph, without any reference to the azimuth of a principal plane; and that the tilt and swing of either wing-photograph can be found from the tilt and swing only of the center photograph, without reference to the azimuths. This feature is important in practical photogrammetric operations, because settings in a rectifying camera for the precise rectifications of photographs are determined from tilt and swing alone, without using the azimuths of the principal planes.

Now I wish to mention very briefly the rather far-reaching possibilities in photogrammetric work, arising from these various sets of formulas. These possibilities would doubtless be apparent to everyone familiar with photogrammetry, after consideration of the formulas themselves.

(1) Since the tilt and swing of any high oblique photograph, such as any of the wing-photographs in trimetrogon photography, can be determined at once from the measured position of the horizon on the photograph, formulas 8.33 make it possible to determine the tilts and swings for all photographs in a trimetrogon strip.

(2) Since two wing-photographs are available in each trimetrogon group, whereas only one is required to find the tilt and swing of the corresponding center photograph, the check provides a means for making new determinations of atmospheric refraction corrections to be applied to measured positions of the apparent horizons.

(3) The tilts and swings throughout a complete strip of trimetrogon photographs furnish data for accurate rectifications of all center strip photographs for the construction of controlled mosaics, if this is desired.

(4) With values determined for the tilts and swings for all photographs in a trimetrogon strip, a computation can very easily be made of the correct horizontal positions through a complete scheme of photogrammetric triangulation covering the entire strip of both center and wing-photographs, based upon one single control line and measurements of image coordinates on the original unrectified photographs, with results entirely free from any errors due to either tilt or topographic relief, without using any templates or plotters.

(5) With tilts and swings known, a scheme of space triangulation, including elevations as well as horizontal positions, can easily be computed through a trimetrogon strip, based upon a single control line with known terminal elevations. Furthermore, the geometric relations between center and wing trimetrogon photographs immediately suggest the design of an auxiliary camera to determine tilts and swings for nearly-vertical aerial photographs taken with a single-lens camera. In fact either wing-camera in trimetrogon photography might be regarded as a counterpart of such an auxiliary camera. However, as an accessory to a single-lens camera, the auxiliary camera might better be much smaller; and instead of having a separate mounting in a fixed relation to that of the principal camera, it might well be built into and a part of the principal camera, so designed that the small auxiliary photograph would merely appear in one corner of the principal photograph. The auxiliary photograph, intended merely for use in determining the tilt and swing of the principal photograph, would need only to show the horizon, and would not need to overlap the principal photograph. The focal plane of the auxiliary camera might therefore be perpendicular to that of the principal camera, and the axis of the auxiliary camera might then be parallel to the x or the y-axis of the principal photograph. The formulas, then, under 8.13, 8.23, 8.33, and 8.43, with θ equal to 90°, would assume the simplified forms shown in groups 8.51, 8.61, 8.71, and 8.81.

(6) With such a single auxiliary camera designed for a single-lens camera, accurate rectification data would become available for all of the nearly-vertical photographs, for precise mosaic construction.

(7) Photogrammetric triangulation for either horizontal positions only, or for space positions including elevations, could be computed through a strip of nearly-vertical photographs, from a single control line, by the application of extremely simple methods. Again, a still further extension of the auxiliary camera idea might be to design a single-lens camera with two small auxiliary cameras, one to record a small photograph showing the horizon in one corner of the principal photograph, as already suggested, and the other to record in another corner a photograph of the sun. Doubtless it would be necessary to construct the second auxiliary camera in such a manner as to permit varying the angle θ between the axis of the auxiliary camera and that of the principal camera.

(8) Then, with such a camera design, the tilt and swing of both the principal photograph and of the second auxiliary photograph could be determined from the first auxiliary photograph showing the horizon. The correct altitude of the sun could then be determined from the second auxiliary photograph, and the azimuth of the sun could be calculated from the altitude. The correct horizontal angle could be found between the sun and the principal plane of the second auxiliary photograph. Then formulas 8.35 and 8.45 would give the azimuth of the principal plane of the principal photograph. Thus the complete space orientation of every principal photograph would be determined instead of only the tilts and swings. This procedure would open entirely new possibilities

in the way of simplifying the computation of photogrammetric triangulation through a strip of photographs.

(9) If the idea of the auxiliary camera were extended still farther, and the single-lens camera were also equipped with a third small auxiliary camera to photograph a time piece in a third corner of the principal photograph to record the exact exposure time, another interesting possibility arises. The altitude of the sun and the exact time of exposure, corresponding to each one of two photographs, one near the beginning and the other near the end of a strip of vertical photographs, in conjunction with a photogrammetric triangulation computation, would furnish observation data for the computation of a "running fix," as explained in detail in text books on practical navigation. The "running fix" would determine the latitudes and longitudes of these two exposure stations, with the same limitations in accuracy as in usual navigation determinations. This information would be extremely interesting, and would be highly valuable in connection with exploration mapping.

Perhaps all, certainly some, of these nine topics deserve investigation.

To summarize, this discussion has been intended to show how problems in photogrammetry arise whenever and wherever the subject is taught. The revised geometry of the aerial photograph, based upon the direction-cosine system of space orientation, produces considerable simplification in the solutions of the fundamental problems of photogrammetry. It also facilitates the derivation of interesting and useful relations between orientations of center and wing-photographs in either trimetrogon or multiple-lens photography. Then these relations, in turn, give rise to numerous possibilities in photogrammetry which merit investigation.

As stated above, the revised geometry of the aerial photograph, including the revised solutions of the basic problems of photogrammetry and the derivations of the above formulas, is now being printed. Illustrative practical computations will be published at an early date.

Research, in connection with the additional topics suggested above, will doubtless be undertaken at Syracuse University, as soon as available time and personnel will permit. Your interest, your suggestions, your criticisms, and your cooperation will indeed be welcome.

APPENDIX I

Statement of formulas

Two sets of space rectangular axes

X, Y, Z rectangular axes used as the data for the survey coordinates of ground points (survey-space-coordinate-axes)

x, y, z rectangular axes used as the data for the photographic coordinates of images on a photograph, with the x- and y-axes coincident with the geometric axes of the photograph, indicated by the camera marks, and with the z-axis coincident with the camera axis (photographic-space-coordinate-axes)

Direction angles of any line with respect to the X, Y, Z axes, are designated by M, N, K; direction angles of any line with respect to the x, y, z axes are designated by m, n, k. These symbols are always followed by the designation of the line itself.

In the direction-cosine system of designating the spatial orientation of an aerial photograph, the elements of orientation may be taken either as the direction-cosines of the survey-space-coordinate-axes, referred to the photographic-space-coordinate-axes, or as the direction-cosines of the photographic-space-coordinate-axes referred to the survey-space-coordinate-axes. The former set is selected. Thus the direction-cosine elements of space orientation of an aerial photograph are denoted by

$$\begin{array}{lll} \cos m\ X & \cos n\ X & \cos k\ X \\ \cos m\ Y & \cos n\ Y & \cos k\ Y \\ \cos m\ Z & \cos n\ Z & \cos k\ Z \end{array}$$

(The angle k Z is identical with the resultant tilt of the aerial photograph.)

7.14 (For any single photograph, Formulas for the direction-cosines of the photographic-space-coordinate-axes, referred to the survey-space-coordinate-axes, in terms of the tilt, swing,

and azimuth of the principal plane of the photograph

$\cos M x = -\cos s \cos \alpha - \sin s \cos t \sin \alpha$
$\cos N x = \cos s \sin \alpha - \sin s \cos t \cos \alpha$
$\cos K x = -\sin s \sin t$

$\cos M y = \sin s \cos \alpha - \cos s \cos t \sin \alpha$
$\cos N y = -\sin s \sin \alpha - \cos s \cos t \cos \alpha$
$\cos K y = -\cos s \sin t$

$\cos M z = -\sin t \sin \alpha$
$\cos N z = -\sin t \cos \alpha$
$\cos K z = \cos t$

7.21 (For any single photograph) Formulas for the direction-cosines of the survey-space-coordinate-axes, referred to the photographic-space-coordinate-axes, or for the direction-cosine elements of orientation of the photograph, in terms of the tilt, swing, and azimuth of the photograph

$\cos m X = -\cos s \cos \alpha - \sin s \cos t \sin \alpha$
$\cos n X = \sin s \cos \alpha - \cos s \cos t \sin \alpha$
$\cos k X = -\sin t \sin \alpha$

$\cos m Y = \cos s \sin \alpha - \sin s \cos t \cos \alpha$
$\cos n Y = -\sin s \sin \alpha - \cos s \cos t \cos \alpha$
$\cos k Y = -\sin t \cos \alpha$
$\cos m Z = -\sin s \sin t$
$\cos n Z = -\cos s \sin t$
$\cos k Z = \cos t$

7.31 (For any single photograph) Formulas for the tilt, swing, and azimuth of the principal plane, in terms of the direction-cosines of the photographic-space-coordinate-axes, referred to the survey-space-coordinate-axes

$\cos t = \cos K z \qquad \tan s = \cos K x / \cos K y \qquad \tan \alpha = \cos M z / \cos N z$

7.41 (For any single photograph) Formulas for the tilt, swing, and azimuth of the principal plane, in terms of the direction-cosine elements of orientation, or of the direction-cosines of the survey-space-coordinate-axes, referred to the photographic-space-coordinate-axes

$\cos t = \cos k Z \qquad \tan s = \cos m Z / \cos n Z \qquad \tan \alpha = \cos k X / \cos k Y$

For trimetrogon photographs, the photographic-space-coordinate-axes of the center photograph are designated by x, y, z, and direction angles for any line referred to these axes are designated by m, n, and k; the photographic-space-coordinate-axes of the left wing-photograph are designated by xl, yl, zl, and direction angles for any line referred to these axes are designated by ml, nl, kl; the photographic-space-coordinate-axesof the right wing-photograph are designated by xr, yr, zr, and direction angles of any line referred to these axes are designated by mr, nr, kr.

For the center photograph, the x-axis is taken as the one which is approximately in the direction of flight; for the wing-photographs the positive y-axis is taken approximately "up the photograph" in each case; and the z-axis is coincident with the camera axis in all cases.

8.13 (For trimetrogon photographs) Formulas for the direction-cosine elements of orientation of a center photograph, in terms of the same orientation elements of either wing-photograph

$\cos m X = \cos ml\, X$
$\cos n X = \cos nl\, X \cos \theta - \cos kl\, X \sin \theta$
$\cos k X = \cos nl\, X \sin \theta + \cos kl\, X \cos \theta$

$\cos m Y = \cos ml\, Y$
$\cos n Y = \cos nl\, Y \cos \theta - \cos kl\, Y \sin \theta$
$\cos k Y = \cos nl\, Y \sin \theta + \cos kl\, Y \cos \theta$

$$\begin{aligned}
\cos m\,Z &= \cos ml\,Z \\
\cos n\,Z &= \cos nl\,Z \cos\theta - \cos kl\,Z \sin\theta \\
\cos k\,Z &= \cos nl\,Z \sin\theta + \cos kl\,Z \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos m\,X &= -\cos mr\,X \\
\cos n\,X &= -\cos nr\,X \cos\theta + \cos kr\,X \sin\theta \\
\cos k\,X &= \cos nr\,X \sin\theta + \cos kr\,X \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos m\,Y &= -\cos mr\,Y \\
\cos n\,Y &= -\cos nr\,Y \cos\theta + \cos kr\,Y \sin\theta \\
\cos k\,Y &= \cos nr\,Y \sin\theta + \cos kr\,Y \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos m\,Z &= -\cos mr\,Z \\
\cos n\,Z &= -\cos nr\,Z \cos\theta + \cos kr\,Z \sin\theta \\
\cos k\,Z &= \cos nr\,Z \sin\theta + \cos kr\,Z \cos\theta
\end{aligned}$$

8.23 (For trimetrogon photographs) Formulas for the direction-cosine elements of orientation of either wing-photograph, in terms of the same orientation elements of the center photograph

$$\begin{aligned}
\cos ml\,X &= \cos m\,X \\
\cos nl\,X &= \cos n\,X \cos\theta + \cos k\,X \sin\theta \\
\cos kl\,X &= -\cos n\,X \sin\theta + \cos k\,X \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos ml\,Y &= \cos m\,Y \\
\cos nl\,Y &= \cos n\,Y \cos\theta + \cos k\,Y \sin\theta \\
\cos kl\,Y &= -\cos n\,Y \sin\theta + \cos k\,Y \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos ml\,Z &= \cos m\,Z \\
\cos nl\,Z &= \cos n\,Z \cos\theta + \cos k\,Z \sin\theta \\
\cos kl\,Z &= -\cos n\,Z \sin\theta + \cos k\,Z \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos mr\,X &= -\cos m\,X \\
\cos nr\,X &= -\cos n\,X \cos\theta + \cos k\,X \sin\theta \\
\cos kr\,X &= \cos n\,X \sin\theta + \cos k\,X \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos mr\,Y &= -\cos m\,Y \\
\cos nr\,Y &= -\cos n\,Y \cos\theta + \cos k\,Y \sin\theta \\
\cos kr\,Y &= \cos n\,Y \sin\theta + \cos k\,Y \cos\theta
\end{aligned}$$

$$\begin{aligned}
\cos mr\,Z &= -\cos m\,Z \\
\cos nr\,Z &= -\cos n\,Z \cos\theta + \cos k\,Z \sin\theta \\
\cos kr\,Z &= \cos n\,Z \sin\theta + \cos k\,Z \cos\theta
\end{aligned}$$

8.33 (For trimetrogon photographs) Formulas for the tilt, swing, and azimuth of a center photograph, in terms of the same orientation elements of either wing-photograph

$$\cos t = -\cos sw \sin tw \sin\theta + \cos tw \cos\theta$$

$$\cot s = \cot sw \cos\theta + \cot tw \sin\theta / \sin sw$$

$$\tan\alpha = \left[\frac{(\sin sw \cos\alpha w - \cos sw \cos tw \sin\alpha w)\sin\theta - \sin tw \sin\alpha w \cos\theta}{(-\sin sw \sin\alpha w - \cos sw \cos tw \cos\alpha w)\sin\theta - \sin tw \cos\alpha w \cos\theta}\right]$$

8.35 (Special).

$$\alpha = \alpha w + \tan^{-1}\left[\sin sw \sin\theta / (-\cos sw \cos tw \sin\theta - \sin tw \cos\theta)\right]$$

8.43 (For trimetrogon photographs) Formulas for the tilt, swing, and azimuth of either wing-photograph, in terms of the same orientation elements of the center photograph

$$\cos tl = \cos s \sin t \sin\theta + \cos t \cos\theta$$

$$\cot sl = \cot s \cos\theta - \cot t \sin\theta / \sin s$$

$$\tan \alpha l = \frac{(-\sin s \cos \alpha + \cos s \cos t \sin \alpha) \sin \theta - \sin t \sin \alpha \cos \theta}{(\sin s \sin \alpha + \cos s \cos t \cos \alpha) \sin \theta - \sin t \cos \alpha \cos \theta}$$

$$\cos tr = -\cos s \sin t \sin \theta + \cos t \cos \theta$$

$$\cot sr = \cot s \cos \theta + \cot t \sin \theta / \sin s$$

$$\tan \alpha r = \frac{(\sin s \cos \alpha - \cos s \cos t \sin \alpha) \sin \theta - \sin t \sin \alpha \cos \theta}{(-\sin s \sin \alpha - \cos s \cos t \cos \alpha) \sin \theta - \sin t \cos \alpha \cos \theta}$$

8.45 (Special)

$$\alpha l = \alpha + \tan^{-1} [-\sin s \sin \theta / (\cos s \cos t \sin \theta - \sin t \cos \theta)]$$

$$\alpha r = \alpha + \tan^{-1} [\sin s \sin \theta / (-\cos s \cos t \sin \theta - \sin t \cos \theta)]$$

8.51 Formulas for direction-cosine elements of orientation of center photograph, in terms of the same orientation elements of either wing-photograph, when $\theta = 90°$

$\cos m X = \cos ml X$
$\cos n X = -\cos kl X$
$\cos k X = \cos nl X$

$\cos m Y = \cos ml Y$
$\cos n Y = -\cos kl Y$
$\cos k Y = \cos nl Y$

$\cos m Z = \cos ml Z$
$\cos n Z = -\cos kl Z$
$\cos k Z = \cos nl Z$

$\cos m X = -\cos mr X$
$\cos n X = \cos kr X$
$\cos k X = \cos nr X$

$\cos m Y = -\cos mr Y$
$\cos n Y = \cos kr Y$
$\cos k Y = \cos nr Y$

$\cos m Z = -\cos mr Z$
$\cos n Z = \cos kr Z$
$\cos k Z = \cos nr Z$

8.61 Formulas for the direction-cosine elements of orientation of either wing-photograph, in terms of the same elements of orientation of the center photograph, when $\theta = 90°$

$\cos ml X = \cos m X$
$\cos nl X = \cos k X$
$\cos kl X = -\cos n X$

$\cos ml Y = \cos m Y$
$\cos nl Y = \cos k Y$
$\cos kl Y = -\cos n Y$

$\cos ml Z = \cos m Z$
$\cos nl Z = \cos k Z$
$\cos kl Z = -\cos n Z$

$\cos mr X = -\cos m X$
$\cos nr X = \cos k X$
$\cos kr X = \cos n X$

$\cos mr Y = -\cos m Y$
$\cos nr Y = \cos k Y$
$\cos kr Y = \cos n Y$

$\cos mr Z = -\cos m Z$
$\cos nr Z = \cos k Z$
$\cos kr Z = \cos n Z$

8.71 Formulas for the tilt, swing, and azimuth of the center photograph, in terms of the same orientation elements of either wing-photograph, when $\theta = 90°$

$$\cos t = -\cos sw \sin tw$$

$$\tan s = \sin sw \tan tw$$

$$\tan \alpha = \frac{\sin sw \cos \alpha w - \cos sw \cos tw \sin \alpha w}{-\sin sw \sin \alpha w - \cos sw \cos tw \cos \alpha w}$$

8.81 Formulas for the tilt, swing, and azimuth of either wing-photograph, in terms of the same orientation elements of the center photograph, when $\theta = 90°$

$$\cos tl = \cos s \sin t$$

$$\tan sl = -\sin s \tan t$$

$$\tan \alpha l = \frac{-\sin s \cos \alpha + \cos s \cos t \sin \alpha}{\sin s \sin \alpha + \cos s \cos t \cos \alpha}$$

$$\cos tr = -\cos s \sin t$$

$$\tan sr = \sin s \tan t$$

$$\tan \alpha r = \frac{\sin s \cos \alpha - \cos s \cos t \sin \alpha}{-\sin s \sin \alpha - \cos s \cos t \cos \alpha}$$

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REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

MANUEL MEDINA, ALFONSO de la O. CARREÑO, and RICARDO TOSCANÓ, with an appendix by CARLOS MARTÍNEZ BECERRILL: La Gravimetría en Mexico; Estudios y Resultados de las Determinaciones Gravimétricas Hechas en la Republica y presentados a la II Reunión Panamericano de Consulta sobre Geografía y Cartografía, Dirección de Geografía, Meteorología, e Hidrología (Mexico), 151 pp., 1944.

This report is in three sections, each by a different author. The author of the first section is Manuel Medina, Chief of the Geographic Division of the Bureau of Geography, Meteorology, and Hydrology in the Department of Agriculture, Mexico. He traces the progress of gravity investigations from 1866 to the present time, and presents an iso-anomaly map based on the latest gravity data at gravity stations in Mexico, reductions for topography and compensation having been made at all stations. A table of principal facts at the stations appears later in the second section but could well have been a part of the first section.

The author of the second section is Alfonso de la O. Carreño, Professor of Geophysical Exploration Methods at the National University of Mexico and Chief of the Bureau of Geology of the National Irrigation Commission. The first part of this section is mathematical, containing the derivation of the potential of the gravity field, the derivation of the principal formulas for theoretical gravity both with and without longitude term, and a discussion of isostatic reduction formulas and anomalies. Then there follows a detailed description of the various kinds of instruments used in making gravity determinations, namely, the principal types of pendulum apparatus and gravimeters with special attention given to the original Eötvös and the Askania types of torsion balance. Some space is also given to the computation and interpretation of results. This section appears to be written chiefly for the exploration geophysicist. The detailed descriptions and diagrams of gravimeters and torsion balances; the discussions of the principles involved; and the discussion of the processing of the results and the illustrated interpretation of them are matters of interest to the exploration geophysicist.

An appendix to the second section is devoted to a demonstration of the fundamental theorem of the simple pendulum, by Carlos Martínez Becerrill of the Bureau of Geographical Research.

The author of the third and final section of the report is Ricardo Toscanó, who gives tables for obtaining the corrections for topography and compensation. Several examples of the use of the tables are furnished. He discusses the formulas he uses. They are essentially the same as those used by Hayford, but are modified for more rapid computation. The author uses seven lettered zones extending from the station to a distance of 200 kilometers and seven numbered zones, extending from there to the antipodes. The division of the zones into compartments is left to the judgment of the computer, although the author makes some suggestions.

The historical note in the first section of this report is a tribute to the determination and diligence of the Mexican scientist in gravity research, while the iso-anomaly map should prove of interest to geologists and geophysicists. Medina points out the important fact that the principal zero-anomaly curve follows closely the volcanic axis in Mexico and he mentions that there are several lesser zero-anomaly curves whose significance is not yet known.

Table VIII gives the principal facts at gravity stations in Mexico and furnishes valuable data for gravity research and study.

Toscanó's Tables I, II, and III (a) and (b) are expressed in tenths of units of the third decimal place of dynes (gals). The results obtained by using these tables are of the same order of accuracy as those obtained by using Hayford's tables. Table IV, mentioned in the text and following III (b), is expressed in units of the third decimal place and is for rapid computation only; hence, one may expect an uncertainty in the third decimal figure of one or more units. Toscanó's tables should be adequate to take care of the correction for topography provided the station is not situated in mountainous country or surrounded by rugged topography. If, however, it is so situated, Zone A, and possibly Zone B, will not, as a rule, give all the correction that the topography warrants. Hayford recognized this fact by using five zones to cover a little more than the area covered by Toscanó's zones A and B.

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Transactions, American Geophysical Union Volume 26, Number III December 1945

THE EARTHQUAKE OF MARCH 27, 1945, ON THE MOSELLE (MISSOURI) FAULT

Albert J. Frank

Abstract--The study of the earthquake centering near Moselle, Missouri, opens up for research a heretofore unnoticed region of seismic activity. The macroseismic data of this earthquake, summarized in the form of an isoseismal map, agree with the interpretation of the seismograms. A geologic survey made in the epicentral region delineates the fault along which both the instrumental and macroseismic results placed the epicenter. A study of the hypocentral depth shows that this fault system might extend to a depth where some have denied faulting. Thus the earthquake gives a hint of structure.

Introduction--On March 27, 1945, at about 20^h48^m (C.W.T.), a phone call was received at the Institute of Geophysical Technology from Ladue Village in St. Louis County inquiring about an earthquake which had been felt at about 20^h45^m; several minutes later the inquiry was repeated from Lambert Airport and before 21^h the Army Engineers at New Haven, Missouri, and Washington, Missouri, reported an earthquake which they felt and heard. "It sounded like a low rumble followed by a sharp blast." The seismograms at the Institute were examined and, to satisfy repeated calls from newspapers, it was hurriedly determined that the earthquake took place about 39 miles west of St. Louis. Subsequent examination of the records from St. Louis, Florissant, and Cape Girardeau showed this very rapid determination to be essentially correct.

The same evening over a hundred questionnaires were sent by the author to postmasters of the towns lying west and southwest of St. Louis; most of these were returned within 30 hours and were the basis for the sending of additional ones which served to delineate better the area and the zones of intensity.

Macroseismic data--The questionnaires were evaluated on the basis of the WOOD-NEUMANN or Modified MERCALLI Intensity Scale [see 1 of "References" at end of paper]. The highest intensity of the shock was found to be III. The isoseists were drawn and it can be seen by referring to Figure 1 that the macroseismic data and the instrumental results agree with each other.

The area in which the quake was felt was found to be over 3,000 sq mi in the following Missouri counties: St. Charles, Warren, Lincoln, Montgomery, Gasconade, Crawford, Washington, Jefferson, and St. Louis--and in the city of St. Louis.

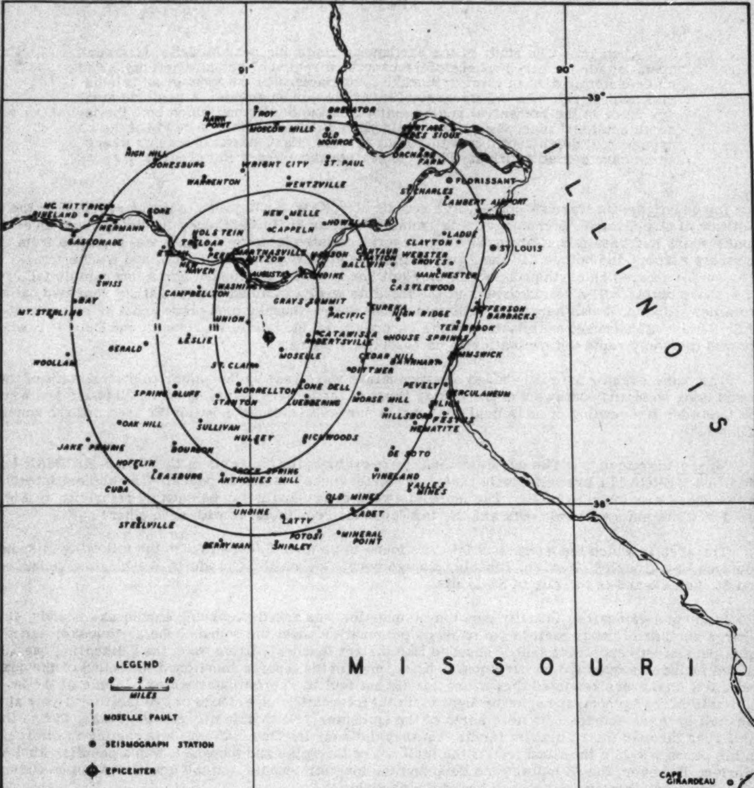
In the questionnaires initially sent out no question was asked regarding earthquake sounds, yet a large number of the reporters volunteered information about the sound of the earthquake; the most most persistent report was that it sounded like distant thunder. Later when the delineating questionnaires included a question on earthquake-noise, most of the reports mentioned the sound of the quake and a few observers reported they heard but did not feel it. Verbal questioning of some of the inhabitants in the epicentral region brought forth the interesting experience of two families living about one-half to three-fourths of a mile north of the epicenter. Neither family felt the quake, though the fault runs through their adjacent farms, but they did hear it. One man who was resting in his rocker on his porch within a thousand feet of the fault heard the noise and thought it was a peculiar kind of thunder; however, the sound was too deep and too long for thunder and the next day when he listened to the reports, he knew that he had heard the earthquake.

Instrumental location of the epicenter--The records from the aforementioned three stations were interpreted with the help of the "Travel Time Tables for Near Earthquakes in East Central North America" compiled during 1941 by EDWARD J. WALTER and HENRY F. BIRKENHAUER at St. Louis University. The data are shown in Table 1.

The three distance arcs obtained by the use of the WALTER-BIRKENHAUER tables intersect in a point approximately three miles northwest of Moselle, Missouri. The geographic position of the point is 90°55′ W and 38°25′ N, a little south of west of St. Louis.

The epicentral distances were checked by the method of calculation outlined by C. F. RICHTER [2]. They were found to be: from St. Louis, 40.0 mi or 64.3 km; from Florissant, 39.8 mi or 64.1 km; from Cape Girardeau, 107.1 mi or 172.4 km.

Geological data--The region lies on the northeastern flank of the Ozark Geanticline. The intersection of the three distance arcs lies very close to the Moselle Fault as recently mapped by the Missouri Geological Survey.


91°
90°
39°
38°
ILLINOIS
MISSOURI
TROY
HARRY POINT
BREMATOR
MOSCOW MILLS
OLD MONROE
PORTAGE DES SIOUX
ORCHARD FARM
RICH HILL
JONESBURG
WRIGHT CITY
ST. PAUL
WARRENTON
WENTZVILLE
FLORISSANT
ST. CHARLES
LAMBERT AIRPORT
MC KITTRICK
RHINELAND
HERMANN
GORE
GASCONADE
NEW MELLE
CAPPELN
HOWELL
HOLSTEIN
TRELOAR
BERGER
NEW HAVEN
PERRY
MARTHASVILLE
DUTZOW
AUGUSTA
DOBSON
CENTAUR STATION
WEBSTER GROVES
BALLWIN
KLONDIKE
LADUE
CLAYTON
ST. LOUIS
SWISS
WASHINGTON
CAMPBELLTON
MANCHESTER
CASTLEWOOD
BAY
MT. STERLING
GRAYS SUMMIT
EUREKA
PACIFIC
HIGH RIDGE
JEFFERSON BARRACKS
UNION
TEN BROOK
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II
III
LESLIE
CATAWISSA
ROBERTSVILLE
HOUSE SPRINGS
GERALD
MOSELLE
CEDAR HILL
BARNHART
KIMMSWICK
WOOLLAM
ST. CLAIR
DITTMER
PEVELY
SPRING BLUFF
MORRELLTON
LONE DELL
HERCULANEUM
STANTON
LUEBBERING
MORSE MILL
HILLSBORO
FESTUS
OAK HILL
SULLIVAN
HEMATITE
JAKE PRAIRIE
BOURBON
HULSEY
RICHWOODS
HOFFLIN
DE SOTO
LEASBURG
ROCK SPRING
ANTHONIES MILL
VINELAND
CUBA
VALLES MINES
OLD MINES
UNDINE
CADET
STEELVILLE
LATTY
POTOSI
MINERAL POINT
BERRYMAN
SHIRLEY
CAPE GIRARDEAU
LEGEND
0 5 10
MILES
MOSELLE FAULT
SEISMOGRAPH STATION
EPICENTER

Fig. 1--Earthquake on the Moselle Fault, March 27, 1945, with isoseists on WOOD-NEUMANN scale

The author spent several days with ROSS R. HEINRICH making a geophysical and geological survey of over half of the fault region. In the geological sketch, Figure 2, the fault as actually traced is drawn as a solid line. Roubidoux sandstone is faulted against Gasconade dolomite. The throw of the fault is at least 50 feet though probably it is much greater. The western or southwestern side of the fault exhibits Roubidoux sandstone at the surface as shown in the sketch, but on this side the sandstone is only several feet thick, being underlain by the Gasconade dolomite which is exposed in cuts, whereas on the eastern side the sandstone is more than 50 feet thick; some distance from the fault the Roubidoux is overlain by Jefferson City dolomite. In addition the field work shows that the trend of the fault, at least in the region where the fault is shown as a solid line on the map, is more northwest-southeast than previously supposed.

Table 1--Data regarding the earthquake

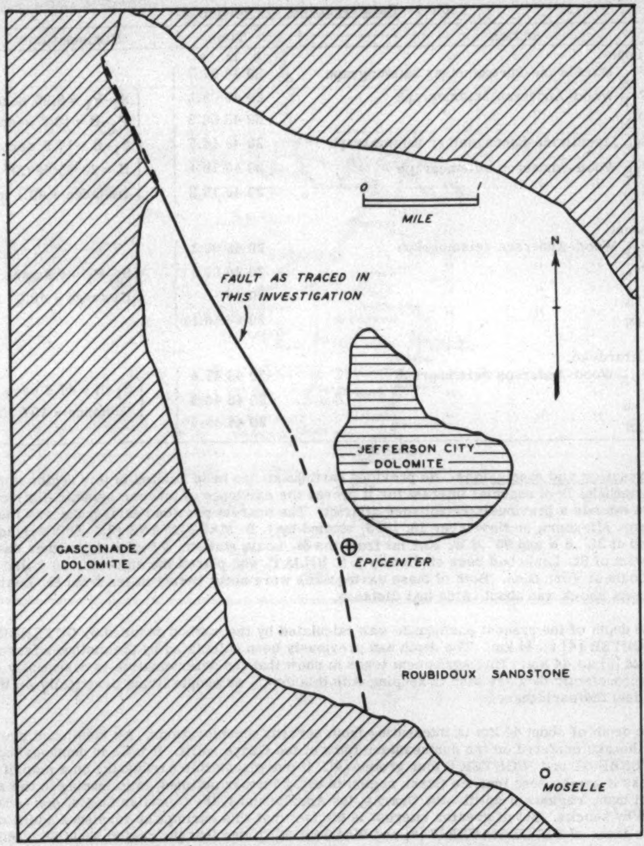
Station	Time	Computations
Saint Louis:	h m s	
iP_{1Z} Macelwane-Sprengnether seismograph	20 46 07.7	S_1-P_1 = 6.95 secs. P_1-H = 10.8 secs. S_1-H = 17.8 secs. H = $20^h45^m57.9^s$ Distance = 40.1 mi.
iP_{1E} Wood-Anderson seismograph	20 46 09.2	
iP_{1N} " " "	20 46 08.2	
iS_{1Z} Macelwane-Sprengnether seismograph	20 46 14.5	
iS_{1E} Wood-Anderson seismograph	20 46 16.1	
iS_{1N} " " "	20 46 15.2	
Florissant:		
iP_{1E} Wood-Anderson seismograph	20 46 09.1	S_1-P_1 = 6.9 secs. Distance = 40.07 mi.
iP_{1N} " " "	20 46 09.11	
iS_{1E} " " "	20 46 16	
iS_{1N} " " "	20 46 16.11	
Cape Girardeau:		
$eS_{?E}$ Wood-Anderson seismograph	20 46 45.4	S_1-H = 47.8 secs Distance = 107.3 mi.
eS_{1E} " " "	20 46 46.3	
iS_{1N} " " "	20 46 45.4	

Discussion and conclusions--No previous earthquake has been studied in this region and thus this earthquake is of especial interest for it proves the existence of another seismic district or perhaps extends a previously established district. The nearest previous earthquake was the one at Grover, Missouri, on November 16, 1933, studied by J. B. MACELWANE [3]. This earthquake centered at 38°.6 N and 90°.6 W, 20.1 mi from the St. Louis station. Previously another earthquake west of St. Louis had been studied by J. S. JOLIAT, who placed the epicenter 18 miles west of St. Louis at Fern Glen. Both of these earthquakes were about twenty miles from St. Louis while the present shock was about twice that distance.

The depth of the present earthquake was calculated by the method deduced by GUTENBERG and RICHTER [4] as 44 km. The depth had previously been calculated by the method advanced by OLDHAM [5] as 44 km. This agreement tends to show that the determination is essentially correct. The macroseismic data are also in keeping with this depth, as people living practically on the fault did not feel the earthquake.

The depth of about 44 km is interesting from several considerations. As mentioned previously, the earthquake centered on the northeastern flank of the Ozark uplift. It falls in depth-group three of GUTENBERG and RICHTER'S four groups [4]. If one places this earthquake on a map of selected shocks it can be seen that the Ozark region is being further outlined, thus leading to the supposition that many regions of uplift--the Ozarks, the Appalachians, the Canadian Shield, etc.--can be outlined by shocks. But of greater interest is the fact that this earthquake furnishes additional evidence in favor of BIRKENHAUER'S [6] and WALTER'S [7] idea that the region about St. Louis has unusual structure. The crustal picture west of St. Louis has never been determined in detail, but if the MOHOROVIČIĆ discontinuity exists at the same depth as WALTER and BIRKENHAUER found it south and east of St. Louis, namely 37 kilometers (from their previously-mentioned tables), then this earthquake originated in the normal substratum beneath the surface layers. Even though the MOHOROVIČIĆ discontinuity were deeper, or the focus perhaps a few kilometers shallower, all the surface layers would still lie above the center of origin. We may also form the important conclusion that the initial arrival-times in the tables of WALTER and BIRKENHAUER, constructed for the regions south and east of St. Louis, can be extended to cover near earthquakes for the region west of St. Louis even though the structure is probably different. This latter possibility is indicated by the number and character of impulses which follow the initial phases.

Yet another factor should be considered. As previously implied, the earthquake certainly did not originate through any slippage along the Moselle Fault as expressed at the surface, yet the fact that the epicenter was located by both macroseismic and instrumental methods as being within a thousand feet of the Moselle Fault suggests that there must be some relationship between the fault and the earthquake. It is believed that the surface fault is merely the expression of active forces operating beneath the crustal layers.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DOLOMITE
GASCONADE
DOLOMITE
EPICENTER
ROUBIDOUX SANDSTONE
MOSELLE

Fig. 2--Geological sketch of the epicentral region

Two maps [8,9] of the faults in the basement complex show the St. Mary's Fault zone with an extension in the direction of the Moselle region. The present earthquake indicates that the fault zone, of which the St. Mary's Fault is one expression, branches farther north than was known and includes the Moselle Fault. There may even be other, as yet unknown, surface expressions of this deep seated faulting.

Acknowledgements--The author wishes to express his thanks to JAMES B. MACELWANE, and particularly to ROSS R. HEINRICH, for assistance in the preparation of this paper. He also thanks all those who responded to the questionnaires.

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[6] HENRY F. BIRKENHAUER, The Illinois Basin earthquake of November 23, 1939, author's abstract, Earthquake Notes, v. 12, Nos. 1 and 2, p. 15, 1940.

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[8] SPECIAL COMMITTEE ON GEOPHYSICAL AND GEOLOGICAL STUDY OF CONTINENTS, Report of, Trans. Amer. Geophys. Union, Part I, pp. 9-12, 1936. Reconnaissance map showing approximate configuration of surface of basement crystallines for United States.

[9] Reconnaissance map showing approximate configuration of surface of basement complex, Amer. Geophys. Union Special Exhibit, 1939.

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NOTES AND PERSONALIA

(See also pp. 387, 388, 390, 429, 430, 440, 444, 455, 456, 458, 459, 460, and 462)

NOTES

International Union of Geodesy and Geophysics--A meeting of the Executive Committee of the International Union of Geodesy and Geophysics, consisting of the officers of the Union, was convened at Oxford, England, December 10-17. Following recent precedent, secretaries of Associations were invited to attend and also certain others whose presence was desirable, in order to provide proper representation of each Association. Those in attendance from America were J. A. Fleming, President of the Association of Terrestrial Magnetism and Electricity; R. M. Field, Chairman of the Commission on Continental and Oceanic Structure; and W. D. Lambert of the Bureau of the Association of Geodesy. Unfortunately, N. H. Heck, President of the Association of Seismology, did not find it possible to attend, nor did J. Bjerknes, Secretary of the Association of Meteorology. England, France, Holland, Italy, Norway, and Switzerland were also represented by members of the Executive Committee or by secretaries of Associations. It is hoped to publish a summary of the proceedings in the next number of the Transactions. The agenda for the meeting included administration (elections of President and General Secretary, time and place of next General Assembly, and resumption of payment of dues), together with consideration of a report on the war years by General Secretary Winterbotham. Much consideration was given to proposals by National Committees and decisions of recommendations received from the General Secretary of the International Council of Scientific Unions as regards matters of policy of Unions as a whole and of the International Union of Geodesy and Geophysics in particular, and such other business as was necessary in the arrangements for the resumption of the full functions of the International Union.

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

V. CONRAD: Methods in climatology. Cambridge, Massachusetts, Harvard University Press, xx + 228 pp., 46 figs., 48 tables, 1944.

This is the first book of its kind in the English language, and is unusually detailed and complete. It is divided into four main parts as follows: (I) General methods; (II) Representation of characteristic features of different elements; (III) Methods of spatial comparison; (IV) The climatography.

Part I discusses first the observation of meteorological phenomena, with regard to methods, station networks, sources of error, and the comparability of climatological series. Next, there is a discussion of "General statistical characteristics of climatological elements," introducing such statistics as the median, quartiles, mode, extremes and range, etc., followed by "Special statistical characteristics of climatological series," introducing the mean and variance, the normal distribution and a simple measure of departure from normality, skewness, "The method of random samples," and other elementary statistical concepts and methods. Finally, there is a discussion of curve-fitting and smoothing and of harmonic analysis.

Part II applies the concepts and methods described in Part I to temperature and pressure, wind, cloudiness, precipitation, and some "combined elements," for example, relative humidity.

Part III discusses methods of comparison of observations taken at different stations, such as by maps showing isograms, by means of anomalies, and so on, devoting a chapter to correlation and regression and another to criteria of relative homogeneity, the definition of a "normal period" and the reduction of climatological averages to a certain period, including interpolation of missing data and the definition of climatically coherent and incoherent regions. Also there are some remarks on air-mass climatology and on numerical characterization of climatic features, such as continentality.

Part IV indicates what topics should be covered, and with what degree of detail, in the composition of a climatography.

In addition to the four main parts of the book, there is a preface, a detailed table of contents with lists of tables and illustrations, an index, and four appendices giving forms of individual climatic tables and frequently used tables, such as the numbers of the days of the year.

Besides its general completeness and attention to detail, this book has several praiseworthy features, such as emphasis on the importance of choosing empirical formulas to fit the boundary conditions, completeness of arithmetic in examples of the use of statistical methods, and discussion of sources of error in climatological series, for example, instrumental defects. Also there are many figures, many references to the literature, and the book is printed in very legible type with few typographical errors.

This volume is chiefly an elementary textbook of statistics written for a special field (in this case, climatology), over one-third of it being given to purely statistical discussion, though always in the language of, and with examples from, climatology. As such, it is one of a large group of books which have appeared in recent years, and shares their faults. It contains many statements, usually statistical, which are false, incomplete, lacking in clarity, or empty. These are important not so much individually or intrinsically but because they tend to defeat the purpose of the book. That purpose is to stimulate interest in statistical methods and, especially, in their application to climatology. However, many of the very students most worth encouraging will be able to recognize such statements, and no doubt some will be completely alienated.

A few examples may serve a useful purpose. The discussion and use of class limits is deplorably confused and imperfect. For example, at the top of page 26, it is said that, ", . . . 1C° is chosen as a suitable size for the class intervals," but at the bottom of the same page, while discussing the same example, we read, ". . . . the interval of 0.9°C. . . ," and on page 27, the two "equations" $11.0 + 0.9 \times 0.05 = 11.04C^\circ$ and $10.9 + 1.0 \times 0.05 = 11.04C^\circ$ occur connected merely by "or" ( ), implying that we may use either of two incorrect lower limits for the class, and either an incorrect or a correct value for the class interval, and get the same answer to two decimals. The correct equation is, of course, $10.95 + 1.0 \times 0.05 = 11.00$.

On page 33 it is said that the standard deviation ". . . is the best and most exact measure of scattering." Since "best" and "exact" are undefined, the statement is essentially meaningless, but readers of an elementary text might be expected to suppose the standard deviation "best" regardless of the source of the data, of the kind of variation exhibited by the data, or of the use to which the measure of scattering is to be put. On page 35 it is said that the mean, median, and mode coincide ". . . only if there is a normal distribution of frequency. . ." However, this is true for any symmetrical distribution, the only qualifications being that there may be an anti-mode rather than a mode, or perhaps no mode at all, and that the mean may not exist.

(Concluded on page 358)

Transactions, American Geophysical Union **Volume 26, Number III** **December 1945**

STEAM-FOG OVER LAKE MICHIGAN IN WINTER

Phil E. Church

Abstract--From surface-water and air temperatures 7m above the water, it was found that over Lake Michigan in winter, a vapor pressure difference of about 5 mb between air and surface water was necessary for "steam-fog" to form when the water was between 0° and 5°C. With a smaller vapor pressure difference there was no "steam-fog;" with a greater difference than 5 mb there was dense "steam-fog." The wind-velocity and lapse-rate determined the character of its appearance after "steam-fog" had formed. Conditions favoring its formation over the lake are most frequent in January. There are fewer occurrences in December, February, and November.

Introduction--In making routine trips across Lake Michigan on railroad-car ferries for gathering lake temperatures [see 1 of "References" at end of paper], the writer became interested in steam-fog ("steam") because of the frequency of its appearance during the winter. Though on most of the crossings there was none, on others there would be some, occasionally a blanket so dense and of such vertical thickness that navigation was greatly handicapped.

Several have given some thought to this phenomenon. WILLETT [2] classifies steam-fog as an air-mass fog of advection type and explains its presence as the result of the air becoming saturated by direct evaporation from the water where the temperature of the water is higher than the temperature of the air. He states further that the air temperature must be colder than -6.0° or -8.0°C before steam-fog may form, that also necessary is a marked inversion, and that the density of the fog is dependent on the rapidity of saturation of the air. The density, he states, is determined by (1) the magnitude of the difference between air and water temperature, (2) the air temperature itself, and (3) the absolute humidity of the air.

BYERS [3] has given specific values of temperature and vapor pressure for both water and air in illustrating the conditions necessary for formation of this fog. As an example he states that if the air had a temperature of 5°C and a relative humidity of 75 per cent its vapor pressure would be 6.54 mbs, but at saturation the vapor pressure would be 8.72 mbs. If the unsaturated air were in contact with a water surface of $T = 10°C$, whose vapor pressure would be 12.28 mbs, the saturation vapor pressure of the air would be 3.56 mbs less than the vapor pressure of the water. Under such conditions, the surplus vapor evaporated from the water surface, above that needed to saturate the air, would condense as steam-fog. If an inversion were present the fog would collect as a blanket, the vertical height of which would be limited (under calm air) to the saturated layer of air. Upward transport would be prohibited by atmospheric stability. BYERS is of the opinion that a strong inversion, together with light winds, is necessary for concentration of the fog near the surface, though admittedly fog can form in a high wind velocity. Under this latter situation turbulence would distribute the fog upward.

PETTERSSEN [4] gives the cause of its formation as $E \gg E_a$, where E is saturation pressure of aqueous vapor above liquid water and E_a that of the air. Under this condition "water would evaporate quickly and fill the air with vapor, 'steam' would pour forth from the surface and the air would be filled with steam-fog." He adds, "It is important to bear in mind that extreme temperature differences are required to produce a steam-fog," and that "in extreme cases, steam-fogs are known to occur in strong winds."

BYERS [3] partly ascribes the autumn or secondary maximum frequency of fog around the Great Lakes stations (STONE [5]) to steam-fog. The writer, however, has never seen steam-fog flow inland more than 200 m distance from the water before disappearing; it has never reached inland as far as the airports of Milwaukee, Wisconsin, and Muskegon, Michigan.

Conditions during presence of fog--The S. S. City of Milwaukee" is of such design that it was impossible to make any instrumental readings of the air closer to the water than at deck level, seven m above the water line. Hence, unless otherwise noted, all observations were taken at this height. Most of the observations, then, were taken in clear air above the fog, though some were obtained within the "steam" itself. Readings taken on five trips during which steam-fog was present, included the surface temperature of the water, wet and dry bulb temperatures of the air (no wet bulb readings were taken on February 19, 1942 trip), wind velocity and direction, state of sky, and heights of waves. These data are given in Table 1. Wave heights appeared to have no effect on either the formation or structural appearance of the fog, so no entries of this condition have been made in the table.

From Table 1 certain conclusions can be drawn regarding the critical conditions necessary for the formation of this fog:

1. The time of day is immaterial; fog has been observed both day and night.
2. Cloud coverage, also, has no effect on the occurrence of fog.
3. Wind velocity does not appear to have any effect on whether fog will or will not be formed, at least from those wind velocities measured at deck level (seven m) or at crow's nest level (23 m). Fog has been observed at any velocity from calm to Beaufort 6. There is no reason to believe that there is an upper velocity which determines whether fog will or will not be formed.
4. The air temperature (T_a) alone does not appear to be the sole controlling condition. Though on these crossings the highest air temperature in which fog was formed over Lake Michigan was -8.2°C, nevertheless, none was present on a crossing when the air was -10.2°C. Furthermore, dense steam-fog has been observed by the writer over rivers when the air temperature has been close (both above and below) to the freezing point. One such entry of conditions, over a creek in Tennessee, has been included in Table 1.
5. The water temperature (T_w) alone has no effect on whether or not fog will form, at least within the temperature range from 8.6° to 0.0°C, provided the water is not frozen.
6. The temperature difference between air and the water surface similarly is not the significant control. Dense steam fog has been seen with a difference of only 7.2°C, whereas on other occasions none was present with differences of as much as 13°C.
7. No clue is given as to the critical condition of formation by plotting the water temperature against the air temperature because a scattergram (not included) shows no definite cleavage line between the presence or absence of fog in relation to these two temperatures. Steam-fog traces have been observed over water of 0.5°C but the air temperature was lower than -13°C. On the other hand, dense fog has been encountered over water of 3.9°C while the air temperature was only -10.2°C. Lastly, fog has been seen, on numerous occasions, over rivers when the air temperature was above freezing (one example given in Table 1). Because of the variations of temperature of both the air and the water, it is obvious that individually these temperatures are not the controlling features of the formation of the fog. However, there is indication that the vapor-pressure difference may be the essential condition because of a distribution of points such that the lower the air temperature, the lower the water temperature can be at which fog will first form. Furthermore, at a constant air temperature there is an increasing thickness or denseness of the fog as the water temperature increases. With increase of water temperature there is an increase of the vapor-pressure, and, conversely, with decrease of air temperature the lower will be the partial pressure of vapor at saturation.
8. The column of the vapor-pressure difference (E_w-E_a) in Table 1 shows that within rather close limits steam-fog will not be visible until the difference is approximately 5 mb (see Fig. 1). At that vapor-pressure difference only traces appear, but with an increasing vapor-pressure difference the denseness of the fog increases rapidly. Over the lake the greatest vapor-pressure difference was only 6.2 mb; concomittantly there was a dense fog. With a vapor-pressure difference of more than 5.5 mb nearly always there were columns that extended upward into the low stratocumulus cloud deck on the east side of the lake. It is true that these observations over the lake have been limited to relatively low air temperatures.

With the low air temperatures experienced over the lake (in contrast to higher temperatures over rivers) the partial pressure at saturation does not exceed 3 mb. This must be reduced, of course, depending on the relative humidity of the air. On the other hand, at the time that "steam" is most frequent the major body of the lake has a surface temperature between 3° and 5°C or vapor-pressures (at saturation) between 7.58 and 8.72 mb, respectively. Assuming near saturation of the cP or cA air at the time of the appearance of "steam," the air temperature must be so low that it cannot have a vapor-pressure of more than 2.5 to 3.0 mb. The fact that "steam" is more frequent in January and December than in February is easily accounted for, inasmuch as a vapor-pressure difference of at least 5 mb is necessary. During February and early March, when the lake temperature has dropped to less than 2.0°C, the vapor-pressure of the lake is so low (less than 7.06 mbs), that only a very dry air mass will have the small vapor-pressure which will permit a 5 mb difference; hence there are few steam fogs during those two months.

Table 1--Data on steam-fog

No.	Time	Temperature		Vapor pressure of air		Water temp. T_w	V.P. at temp. T_w E_w	Temp. diff. (T_w-T_a)	(E_w-E_s)	(E_w-E_a)	Wind velocity	Character of fog	Steam-fog type
		Dry bulb T_a	Wet bulb	Actual E_a	Saturated E_s								
	h m	°C	°C	mbs	mbs	°C	mbs	°C	mbs	mbs	Beau.		
Cruise 86 - January 5, 1943													
1	06 32	- 8.3	- 8.8	2.47	3.04	2.4	7.26	10.7	4.22	4.79	5	none	0
2	06 50	- 9.4	- 9.9	2.43	2.76	3.2	7.63	12.6	4.86	5.20	5	moderate	3
3	07 17	- 9.4	- 9.9	2.43	2.76	4.2	8.25	13.6	5.49	5.82	5	thick	4
4	07 40	- 9.4	- 9.9	2.43	2.76	4.3	8.30	13.7	5.55	5.87	5	"	4
5	08 10	- 9.7[a]	-10.2	2.36	2.69	3.9	8.07	13.6	5.38	5.71	5	"	4
6	08 40	-10.0	-10.5	2.29	2.62	3.9	8.07	13.9	5.45	5.78	5	"	4
7	09 10	-10.2	-10.7	2.24	2.57	3.4	7.79	13.6	5.22	5.55	5	dense	5
8	09 40	-10.4	-10.9	2.20	2.53	3.5	7.85	13.9	5.13	5.65	5	"	5
9	10 00	-10.6	-11.1	2.16	2.48	3.4	7.79	14.0	5.31	5.63	5	"	5
10	10 25	-10.2	-10.7	2.24	2.57	3.9	8.07	14.1	5.50	5.73	5	"	5
11	10 42	-10.0	-10.5	2.29	2.62	4.1	8.19	14.1	5.57	5.90	4	thick	4
12	11 25	- 9.8	-10.3	2.32	2.67	1.7	6.90	11.7	4.23	4.58	5	traces	1
Cruise 89 - January 13, 1943													
1	03 40	-12.8	-12.8	2.04	2.04	2.3	7.21	15.1	5.17	5.17	3	moderate	3
2	04 00	-12.4	-12.6	1.98	2.12	2.8	7.47	15.2	5.35	5.49	3	dense	5
3	04 20	-11.7	-11.8	2.17	2.25	3.4	7.79	15.1	5.54	5.62	3	"	5
4	04 40	- 9.3	- 9.6	2.59	2.78	3.0	7.58	12.3	4.80	4.99	3	moderate	3
5	05 35	- 8.2	- 8.4	2.84	3.07	3.4	7.82	11.6	4.75	4.88	3	traces	1
6	05 55	- 7.8	- 8.2	2.80	3.17	3.1	7.63	10.9	4.46	4.83	3	none	0
Cruise 92 - January 20, 1943													
2	08 32	-10.4	-11.1	2.08	2.53	2.8	7.47	13.2	4.86	5.39	6	traces	1
3	08 55	-10.1	-10.4	2.40	2.60	3.2	7.68	13.3	5.08	5.28	6	"	1
4	09 25	-10.5	-10.9	2.24	2.51	3.0	7.58	13.5	5.07	5.34	6	"	1
5	09 45	-10.3	-10.5	2.40	2.55	2.8	7.47	13.1	4.92	5.07	6	none	0
6	10 05	-10.2	-10.4	2.46	2.57	2.7	7.42	12.9	4.85	4.96	6	traces	1
7	10 30	-10.0	-10.3	2.41	2.62	2.5	7.31	12.5	4.69	4.90	6	"	1
8	11 18	-11.0	-11.1	2.30	2.40	2.9	7.52	13.9	5.12	5.22	6	moderate	3
9	11 53	-11.2	-11.5	2.16	2.35	3.0	7.58	14.2	5.23	5.42	6	dense	5
10	12 24	-12.5	-12.5	2.10	2.10	2.3	7.21	14.8	5.11	5.11	6	moderate	3
11	12 49	-13.3	-13.4	1.88	1.95	2.0	7.05	15.3	5.11	5.17	5	traces	1
Cruise 16 - February 19, 1942													
1	07 40	-16.8	No readings	1.41[b]	1.41	2.1	7.10	18.9	5.69	5.69	5	dense col.	5
2	08 10	-16.1[a]		1.51[b]	1.51	1.9	7.00	18.0	5.49	5.49	4	" "	5
3	08 50	-15.6		1.58[b]	1.58	1.5	6.81	17.1	5.23	5.23	4	" "	5
4	09 35	-15.6		1.58[b]	1.58	3.1	7.63	18.7	6.05	6.05	4	" "	5
												(ht.200'-300')	
5	10 10	-15.7		1.57[b]	1.57	3.0	7.58	18.7	6.01	6.01	3	" "	5
6	11 10	-15.8		1.55[b]	1.55	3.4	7.79	19.2	6.24	6.24	2	" "	5
7	11 35	-15.6		1.58[b]	1.58	1.6	6.86	17.2	5.28	5.28	2	" "	5
Cruise 93 - January 25-26, 1943													
1	21 13	-13.6	-13.8	1.79	1.90	0.5	6.33	14.1	4.43	4.54	3	traces	1
2	21 40	-12.6	-12.7	2.02	2.08	1.7	6.90	15.3	4.82	4.88	3	"	1
3	21 57	-12.9	-13.2	1.83	2.02	2.3	7.21	16.1	5.19	5.38	3	dense col.	5
4	22 17	-12.2	-12.4	2.02	2.15	2.3	7.21	14.6	5.06	5.19	3	traces	1
5	22 37	-11.6	-11.8	2.15	2.27	2.1	7.10	13.7	4.83	4.95	3	"	1
6	23 07	-11.3	-11.4	2.27	2.33	2.4	7.26	13.7	4.93	4.99	3	"	1
7	23 27	-10.8	-11.0	2.30	2.44	2.1	7.10	12.1	4.66	4.80	3	"	1
8	23 52	-10.4	-10.5	2.47	2.53	2.5	7.31	12.9	4.78	4.84	3	"	1
9	00 12	-10.0	-10.2	2.50	2.62	2.7	7.42	12.7	4.80	4.92	3	"	1
10	00 32	-10.2	-10.4	2.44	2.57	2.6	7.36	12.8	4.79	4.92	3	"	1
11	00 52	- 9.7	-10.0	2.50	2.69	1.7	6.90	11.4	4.21	4.40	3	none	0
12	00 15	- 9.8	-10.0	2.55	2.67	0.5	6.33	10.3	3.70	3.78	3	"	0
13	01 25	- 9.7[a]	-10.0	2.50	2.69	0.1	6.15	9.8	3.46	3.65	3	"	0
14	01 34	- 9.6	-10.0	2.45	2.71	0.0	6.11	9.6	3.40	3.66	3	"	0
In Tennessee (over a creek) - March 17, 1943													
	05 00	+ 1.4	+ 1.0	4.72	6.76	8.6	11.17	7.2	5.41	6.45	1	dense	?

[a] Interpolated. [b] Air assumed to be saturated.

While steam is limited entirely to the winter months over the lake, this phenomenon is of relatively common occurrence elsewhere at other seasons where the essential condition is met in which a warm, wet surface is contacted by air so cold that its vapor-pressure is lower than that of the wet surface. It is doubtful, however, that the critical vapor-pressure difference of 5 mb holds true at air temperatures higher than those observed over the lake. Some common examples of steam-fog at other seasons include that which rises from a hot pavement after a sudden shower, and that which covers ponds and rivers in late summer or autumn when the air temperature is unseasonably low.

Frequency of occurrence--Log books of the railroad-car ferries which operate across Lake Michigan all year, contain some weather information for each trip they make. "Steam" is a phenomenon so striking in appearance, and ofttimes so hazardous to navigation, that whenever it forms its presence is entered in the log. These ships' logs are probably the most accurate record available on the frequency of occurrence of steam-fog over large bodies of water regularly traversed by man. Table 2 shows the number of days "steam" was encountered between Milwaukee and Muskegon for seven winters as recorded in the log of the S. S. "City of Milwaukee" (R. J. MARTIN, Master).

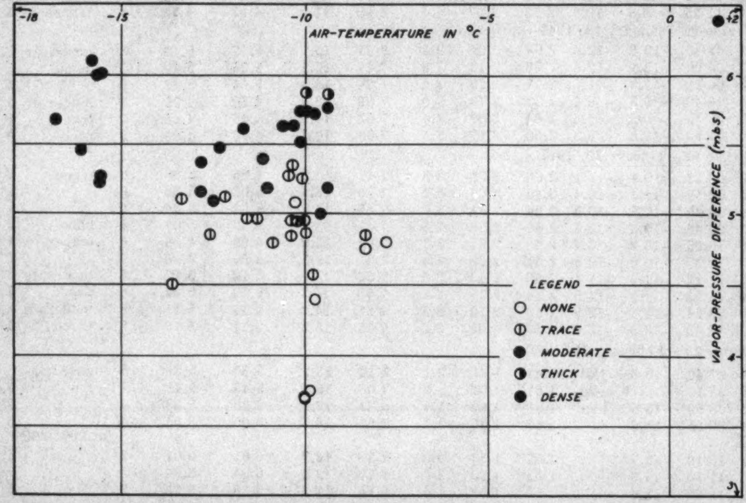

Figure 1--Fog characteristics in relation to air temperature and vapor-pressure difference.

Table 2--Number of days steam-fog reported in log of S. S. "City of Milwaukee"

Year	Nov.	Dec.	Jan.	Feb.
1936	0	3	. . .	. . .
1937	1	2	4	3
1938	0	1	3	2
1939	0	1	5	1
1940	0	2	7	0
1941	1	5	2	2
1942	1	1	6	5
1943	. . .	. . .	4	1
Totals	3	15	31	14
Average no. days per month	0.43	2.1	4.4	2.0

Structural appearance--The character of the fog varied on these crossings from thin patches and traces to a solid blanket of vertical thickness of more than 15 m; more than once there were isolated dense columns which rose at least 100 m in height. In this last case some columns seemed to reach up to the base of the stratus or strato-cumulus deck, a cloud formation nearly always present on the east side of the lake when steam-fog is present over its main body [6].

The following classification is suggested from the characteristics given in Table 3:

Table 3--Classification of steam-fog

Type	Term	Characteristics	Wind velocity
1	Trace	Horizontal coverage less than 0.2 of water surface.	Any
2	Patches	Horizontal coverage from 0.2 to 0.9 of water surface.	Any
3	Moderate (Sheet)	Horizontal coverage complete, but water visible when observer looks down through it. This type usually not more than 5 m thick.	< Beaufort 3
4	Thick (Blanket)	Coverage complete. Water not visible from pilot house (15 m). Short-scattered columns above top of blanket.	< Beaufort 3
5	Dense (sometimes pillars)	Isolated columns or pillars whose diameter is much less than vertical height. Horizontal visibility at deck level within a column is 10 to 20 m. No regular pattern of columns was observed. Wind velocity of Beaufort 3 was lowest velocity these columns have been noticed	>Beaufort 3

While wind velocity plays no direct part in the formation of "steam" it does control the characteristics of its appearance after the fog has formed. With calm and with low velocities up to force 2, the fog lies as a blanket, the upper limit being determined by the gradient of the inversion. With stronger wind, the inversion is less marked and the fog then collects in more or less distinct rows and ascends in "pillars" or columns. Because fog has been observed with all velocities up to and including Beaufort 6, there is no reason to believe that there may be an upper limit beyond which it cannot form.

References

[1] Most of the data for this paper were obtained aboard the S. S. "City of Milwaukee," a car-ferry of the Grand Trunk Railroad which operates between Milwaukee, Wisconsin, and Muskegon, Michigan, while the writer was investigating lake-temperatures for the Department of Meteorology, University of Chicago.

[2] H. C. WILLETT, Fog and haze, their causes, distribution and forecasting, Mon. Wea. Rev., v. 56, pp. 435-468, 1928. See also Descriptive Meteorology, Academic Press, p. 79, 1944.

[3] H. R. BYERS, Synoptic and aeronautical meteorology, pp. 191-192, 1937.

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[5] R. G. STONE, Fog in the United States and adjacent regions, Geog. Rev., v. 26, pp. 111-134, 1936.

[6] C. L. MITCHELL, Snow flurries along the eastern shore of Lake Michigan, Mon. Wea. Rev., v. 49, pp. 502-503, 1921.

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(See also pp. 338, 366, 378, 388, 392, 414, and 450)

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In the footnote on page 35, the author implies that inasmuch as there are but two choices, the probability of each is 1/2. He neglects the fact that circumstances may weigh heavily in favor of one as opposed to the other.

A glance at Figure 6 [p. 38] suffices to discover that it is erroneous, none of the "observed" points being plotted below the fitted curve. Reference to Conrad's original paper shows that the two central points are in error. It also shows that, contrary to the title of the Figure, these two points were not "observed" but result from dividing into equal parts the frequency for these two classes together! The values plotted are perhaps 28 per cent, Table 7 shows that they should total 45.3 per cent, and the original paper shows that they should be 18.9 per cent and 26.4 per cent.

On page 39 Conrad says, "The 'coefficient of variation' should be more frequently used in climatological statistics; it permits an exact comparison of the values characterizing the dispersion because it is reduced to an equal arithmetical mean." An explanation of how it is that the division of a standard deviation by the corresponding mean enables ". . . exact comparison. . . ," would be welcome.

On page 60 we are told, "Here is just the case to use the method of least squares," but Conrad gives no discussion of the circumstances in which the method of least squares is appropriate, nor does he give a reference to such a discussion. On pages 64 and 65, $x = A + By + Cy^2$ is called ". . . the general equation of a conic section. . ." On page 69 we read, "Numerical series should be smoothed only if absolutely necessary," but there is no indication of how to decide whether smoothing is "absolutely necessary."

On page 88 is an example of the estimation of the "true mean" temperature from the extremes for the day which includes a conversion to the Kelvin scale. It would have been more direct to convert the temperature difference in Fahrenheit degrees to Centigrade degrees.

On page 134 in discussing serial independence by means of sequences (S) and changes (C) of sign in a series of deviations, it is said of random series that ". . . in a series with a great number of elements $S - C = 0$. . . ," "When (the series) is small $S - C = 0 \pm \sqrt{n - 1}$." The two statements are obviously incompatible, the first being false, the second true. A footnote to page 135, referring to a series of ten items, says, "Generally, the numbers of elements should be rather greater to permit application of probability criteria." This is true only in the sense that more data are better, probability theory being as applicable to small numbers as to large. The same comment applies to the statement [p. 148] that "In any case, it . . . should exceed 10 years, because otherwise the conclusions from statistical methods are no longer applicable" and [p. 29] ". . . these methods assume their real value only if the size of the sample is . . . many hundreds."

On page 134 is the definition, "A climatological series is relatively homogeneous with respect to a synchronous series at another place if the differences (ratios) of the pairs of the homologous averages represent a series of random numbers which satisfies the normal law of errors." Why normality of distribution is necessary or desirable from a climatological point of view is not discussed, and the two criteria of relative homogeneity offered by Conrad have nothing to do with normality.

The section entitled "Physical explanation of the method of quotients" [p. 143], though it mentions the orographic effects on precipitation, in no wise justifies its title. In meteorological literature, as well as that in various other fields of science, there is much confusion in the use of the terms velocity, which should always be a vector quantity, and speed, which should always be scalar. The author perpetuates this confusion. On page 189 he mentions "direction and velocity," and on page 217 he mentions "resultant velocity (vectorial)" and "average velocity, disregarding direction". . .!

The statement on page 182 that "The comparison of like with like is not valid" is difficult to understand or to connect with the foregoing material.

A more general statistical criticism is of the failure to provide an adequate treatment of tests of significance. Of course, authors have the prerogative of choice and of emphasis. However, though Conrad devotes several pages to "Criteria of relative homogeneity," and, though he gives the random sampling standard errors of two statistics, almost nothing is said about how to use standard errors, and the term "test of significance" does not appear. Later [p. 149] he writes of "climatic divides," but makes no suggestion whatever as to a test for discontinuity. Likewise, the footnote to page 78 ". . . gives a criterion as to whether or not it pays to calculate further terms of the Fourier's series. . . ." attributed to Brunt, but it is no criterion, as Brunt wrote [Met.Mag., v. 72, p. 268, 1937] that if the mean-square departure from the sum of fitted terms ". . . comes out a very small quantity, there can be no further harmonics of appreciable amplitude in the observations." The question of statistical significance (and ultimately that of scientific interest) was not mentioned.

It is to be hoped that a future edition will have the benefit of competent statistical criticism, and that it can be improved in clarity and precision of statement. It could then be recommended without reservation to the novice in statistics and climatology.

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THE FIELD OF VERTICAL MOTION IN SELECTED WEATHER SITUATIONS

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Abstract--The effect of vertical motion on pressure and temperature changes is briefly discussed, and the role of vertical velocities in the process of condensation is stressed. Two independent methods for the measurement of vertical velocities are outlined, and a practical technique for computation is described. The effect of vertical velocities in bringing about changes in sky condition and weather is illustrated in two cases. The field of vertical velocity from the surface to thirteen kilometers through a Colorado Low is illustrated by means of a cross-section showing in the vertical plane the projections of streamlines of air flow, pressure changes, type of temperature advection, and the locations of the tropopause and the trough line.

Introduction--Although the importance of vertical motion in cloud formation is well known, current techniques of constant level or constant pressure analysis do not afford a direct measure of the vertical component of motion. For this reason, even though the extension of upper air analysis has resulted in a better understanding of horizontal air flow changes with height, it has contributed little to more thorough understanding of vertical motion. In fact, due to the lack of a convenient technique for computing vertical motion, discussions of temperature and pressure changes occurring aloft have often neglected this effect [see 1, 2, and 3 of "References" at end of paper]. Consideration of the effects of widespread, uniform vertical motion demonstrates that these effects are so important that they cannot properly be neglected.

Air is highly compressible and with certain exceptions obeys the adiabatic law; therefore, changes in pressure undergone by an air-parcel are proportional to changes in temperature. When unsaturated air moves along a horizontal surface it normally follows approximately an isobaric channel, and therefore experiences very little pressure change and consequently very little adiabatic temperature change. If, however, the flow is not strictly along a horizontal surface, but is inclined downward at such an angle that the vertical component of velocity is -1 cm sec^{-1}, the resulting pressure increase (following the parcel) of 40 millibars in twelve hours will be accompanied in the lower troposphere by an adiabatic temperature-increase of about four degrees Centigrade. Unless the existing lapse rate of temperature approaches the dry adiabatic, this vertical velocity will bring about changes in the density of the air-column which cannot be anticipated by extrapolation on constant level charts.

The magnitude of the horizontal component of velocity at all levels is usually hundreds of times the magnitude of the accompanying vertical component. However, the relative importance of the two components in bringing about changes in weather is frequently just the reverse. Air may move horizontally thousands of miles without undergoing any change that could be called a change in weather. At the same time, an upward movement of only one thousand feet may cool air sufficiently to bring about a thick overcast and heavy rain.

In investigations covering the past eight months the Army Air Forces Research Weather Station at New York University, working in cooperation with the Department of Meteorology, has achieved some success in measuring vertical velocities in the atmosphere and in relating vertical velocities to condensation observed simultaneously or several hours later. It is the purpose of this paper to describe the field of vertical velocity in selected situations, and to demonstrate the relationship between vertical velocity and condensation.

Two methods for measuring vertical velocities--Historically, the first attempts to measure vertical velocities followed the kinematic method [4, 5]. Since the atmosphere is bounded at the bottom by the earth, forced vertical motions may be computed from the horizontal wind speed and the slope of the terrain in the direction of the wind. And since continuity conditions are met by the atmosphere, analysis of the wind flow in the horizontal affords a description of the flow in the vertical. Direct measurements of the slope of the terrain and of the horizontal component of wind velocity at various levels, in theory at least, may be converted into a complete description of the field of vertical velocity according to the following expression [6]:

$$w_1 = w_o(p_o/p_1)^{1/\Gamma} - (\bar{p}/p_1)^{1/\Gamma} \operatorname{div}_2 V \Delta z$$

The subscripts 1 and o refer to the top and bottom of the layer respectively; w indicates vertical velocity; $\bar{p}$, mean pressure for the layer; $\operatorname{div}_2 V$, mean horizontal velocity divergence for the layer; Γ, the ratio of the specific heats of dry air; and Δz, the depth of the layer.

Other attempts to measure vertical velocities in the atmosphere have followed the adiabatic method [4, 6, 7, 8, 9]. Since air is compressible and obeys the adiabatic law, changes in temperature or pressure undergone by an air-parcel at constant potential temperature are for the most part proportional to changes in height. By tracing the movement of an air-parcel through a period of time by its horizontal trajectory and its constant potential temperature, it is possible to convert the pressure or temperature change into units of vertical velocity. The non-adiabatic temperature change which accompanies condensation or evaporation may be overcome in theory by following the equivalent potential temperature of the parcel rather than the potential temperature; however, this refinement is not immediately practicable because of limited accuracy in humidity measurements, local variations in humidity, and because the same value of equivalent potential temperature sometimes occurs at more than one level.

The use of the kinematic method is limited to periods when upper air wind reports are available while the adiabatic method usually can be used even during periods of precipitation.

The isentropic chart affords a satisfactory practical technique for measuring adiabatic pressure or temperature changes by the adiabatic method. Using observed winds wherever possible, streamlines are accurately drawn on the isentropic charts at the beginning and end of the 12-hour period. The trajectory is derived by drawing a line parallel to the initial streamlines at the beginning of the trajectory, parallel to the intermediate wind as it passes the station, and parallel to the final streamlines at the end of the trajectory. By subtracting the pressure of the isentropic surface at the beginning of the trajectory from that at the end, the net vertical motion may be computed with only small error by dividing by the vertical pressure gradient (assumed constant for each 100 mb interval). The computed value may be plotted at the station as an average vertical velocity for the period.

Vertical motion may be computed in an analogous manner from constant level or constant pressure charts or from observations made at a single station [6, 9].

Application of the kinematic method--Figure 1 shows the horizontal distribution of vertical velocity at 8000 feet as computed from observed winds together with the sky condition and weather prevailing at about the same time. It will be observed that upward velocities occupy the western and southeastern portions of the chart, while downward velocities occupy a section through the middle of the chart. Figure 2 shows the same field of vertical velocity together with the sky condition and weather twelve hours later. The area of upward velocities shows widespread development of cloudiness, showers, and thunderstorms, while in the area of downward velocities the sky has become almost entirely clear.

Application of the adiabatic method--Figure 3 shows the field of vertical velocity as measured on the 302° isentropic surface over the southern half of the chart and on the 296° isentropic surface over the northern half of the chart. For the most part upward velocities prevail in regions of precipitation, while downward velocities prevail in regions of clear sky. However, near the western edge of the chart and in the north precipitation is occurring in areas of downward velocity. Figure 4 shows the same field of vertical velocity together with the sky condition and weather twelve hours later. Precipitation has ceased in the extreme west and increased in the areas of upward vertical velocity. Showers still continue in the north, but soundings show that the saturated air is restricted to the first two kilometers with dry air at the 296° surface.

Vertical cross-section through a Colorado low--The period from November 24 to November 26, 1944 was selected for thorough study of the field of vertical motion since it seemed typical of storms frequently appearing east of the Rocky Mountains. Twelve-hour mean vertical velocities were computed at eight isentropic levels giving uniform coverage from gradient level to thirteen kilometers.

On November 24 a Pacific occlusion moved eastward over the coastal ranges. Little difference in the densities of the two air-masses was detected, but a normal band of precipitation followed the front. As the occlusion moved over the Rockies, a closed cyclonic circulation developed southeast of Denver, precipitation spread rapidly to the east, and finally a wave-shaped frontal system became apparent centered at the pressure minimum. Figure 5 shows the surface map after cyclogenesis had

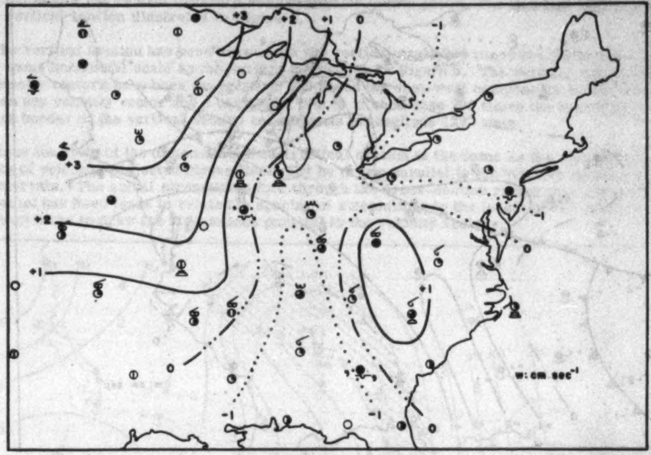
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Fig. 1--Clouds and precipitation, November 1, 1944, at $12^{h}30^{m}$Z (Greenwich Meridian Time) with the horizontal distribution of vertical velocity at 8,000 feet occurring at about the same time ($16^{h}00^{m}$Z)

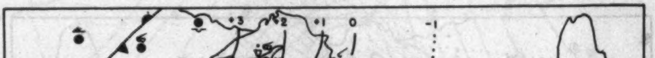
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Fig. 2--Clouds and precipitation, November 2, 1944, at $00^{h}30^{m}$Z with the same horizontal distribution of vertical velocity shown in Fig. 1

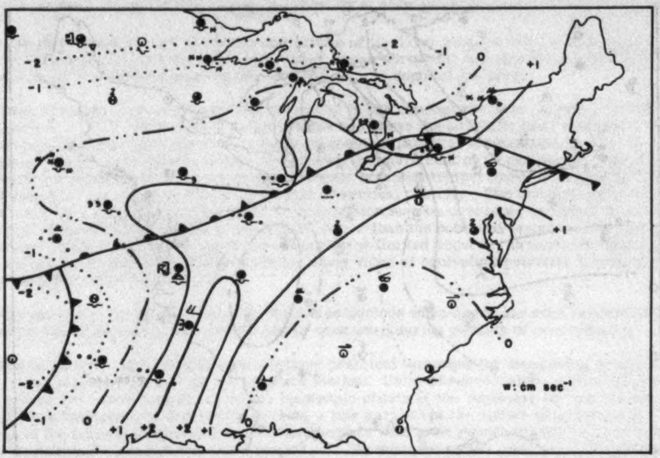

Fig. 3--Clouds and precipitation, March 3, 1944, at 18^{h}30^{m}GMT with the field of vertical velocity at the 302° isentropic surface (southern half of chart) and the 296° isentropic surface (northern half of chart) occurring at about the same time (22^{h}00^{m}GMT)

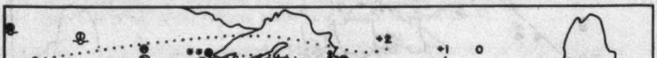

Fig. 4--Clouds and precipitation, March 4, 1944, at 06^{h}30^{m}GMT with the same field of vertical velocity shown in Fig. 3

begun but before the central pressure had reached its lowest point. The line BB′ indicates the axis of the vertical section illustrated in Figure 6.

The vertical section has been drawn with the vertical scale 200 times the horizontal scale, and to the same horizontal scale as the surface map shown in Figure 5. The vertical components of the velocity vectors have been exaggerated 200 times the east-west components so that the slope between any velocity vector and a horizontal line is in each case 200 times the true slope. The western border of the vertical section corresponds to longitude 127° west.

Since the ratio of the dimensions of the vertical section is the same as the ratio of the two components of velocity, projected streamlines may be drawn parallel to the velocity vectors at convenient intervals. The actual streamlines flow through the cross-section rather than along it; and so no attempt has been made to relate the spacing of streamlines to the length of the velocity vectors. Care was taken to draw the streamlines parallel to the velocity vectors.

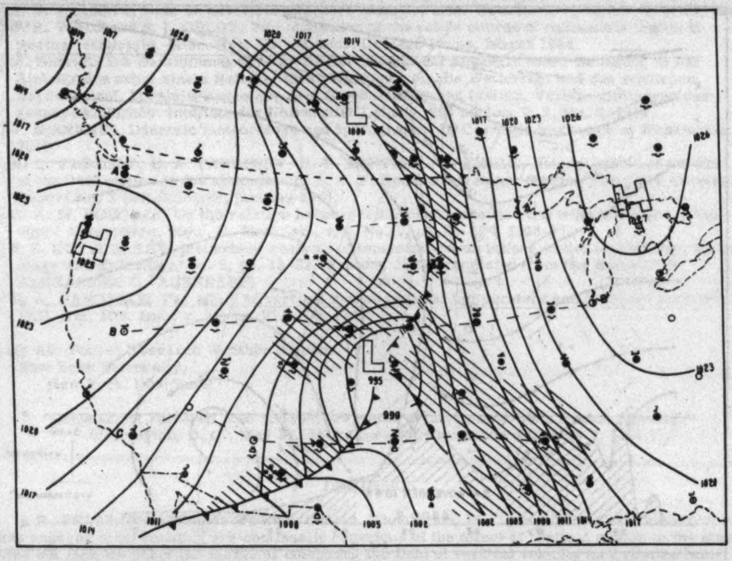

Fig. 5--Surface map after cyclogenesis had begun, November 25, 1944, at 00^h30^m GMT

Since the east-west component of velocity is normally much greater at high levels than near the surface, casual inspection of the chart may give a false impression of the relative vertical velocities at different levels. Recalling that the vertical velocity is directly proportional to the vertical component of the vector, and not alone to the slope which the vector makes with the horizontal, should enable the reader to avoid this pitfall.

Velocity vectors with a small zero at the center (—o—›) indicate zero temperature advection in the horizontal; velocity vectors with a small plus sign at the center (—+—›) indicate warm air advection, while plain velocity vectors (——›) indicate cold air advection. Velocity vectors were not computed where the trajectory of the air was doubtful.

The mean pressure trough line for the twelve-hour period is indicated by a line of small circles. Dashed lines representing four millibar isallobars are drawn for values of +2 and +6 millibars $(12\ hr)^{-1}$. Isallobaric maxima and minima are indicated in the case of closed systems. The positions of the tropopause at the beginning and end of the period are indicated by dotted lines and are labelled respectively 1 and 2.

Each velocity vector is plotted at the height of the isentropic surface from which it was computed. Therefore, the stability of the air at any point relative to that at other points may be judged by the vertical spacing of the velocity vectors, wide spacing indicating instability and close spacing indicating stability. Where a vector has been omitted due to doubtful data, a small cross has been placed at the height of the isentropic surface.

Regions of divergence (horizontal velocity divergence), occurring in a vertical cross-section, usually may be identified by a decrease in the upward velocity with height (negative $\partial w/\partial z$), although the change of density accompanying vertical motion contributes slightly to the vertical velocity without contributing to the divergence. Conversely, convergence usually may be identified in a vertical cross-section by increasing upward velocity with height (positive $\partial w/\partial z$). For the most part, horizontal divergence occurs with streamlines which approach each other in the vertical section while convergence occurs with streamlines which spread apart. In general, divergence as represented by streamlines in the vertical is the opposite of divergence as represented by streamlines in the horizontal.

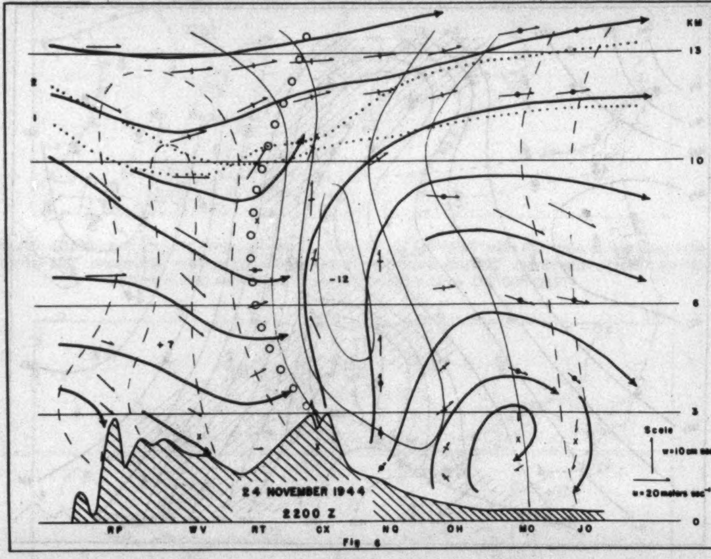

Fig. 6--Vertical section along the line BB′ of Fig. 5, November 24, 1944, at $22^{h}00^{m}$ GMT

The outstanding features of the vertical section are the large scale downward velocities to the west of the trough line, the even more pronounced upward velocities near the center of the cyclone, and the closed vertical circulation to the east of the storm. The maximum downward velocities are about 5 cm $\sec^{-1}$ while the maximum upward velocities are about 8 cm $\sec^{-1}$. The regions of greatest divergence are just below the tropopause to the east of the trough line and just above the surface over Joliet, Illinois. The regions of greatest convergence are just below the tropopause to the west of the trough line and just above the surface over North Platte, Nebraska.

Conclusions--The quick and accurate determination of vertical velocities in the lower atmosphere is central to the problem of making short range forecasts of cloudiness and precipitation. As has been illustrated in this paper, the relationship between vertical velocity and changes in weather is so intimate that a forecasting method based on the determination of vertical velocities gives promise of accuracy not generally attained under methods in use at present.

The effect of vertical velocities on temperature and pressure changes is sufficiently great that attempts to describe atmospheric processes by horizontal flow alone cannot be wholly successful. Only through consideration of the flow pattern in the vertical, together with the flow pattern in the horizontal, can meteorologists hope to attain a thorough understanding of the complex processes attending our everyday weather.

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DISCUSSION

J. R. FULKS (United States Weather Bureau, Washington, D. C., August 6, 1945.)--Meteorologists engaged in forecasting are continually conscious of the effect of vertical motion in the atmosphere but lack the practical means of computing the field of vertical velocity on a routine basis. Of first interest from a forecast standpoint would be some means of predicting the vertical movement that will take place during a forecast period. We have as yet no practical way of doing this. However, as the author shows, a knowledge of the current vertical velocities has some direct prognostic value due to time lag in the occurrence of correlated weather.

The author determines the net vertical motion over a twelve-hour period, and this will normally require some forward extrapolation to obtain the current field. In order to know to what extent extrapolation is valid or to what extent the future field of vertical motion may be correlated with such predictable factors as the future pressure distribution, considerable experience with the method will be necessary. If further experience shows that (1) reasonable extrapolations can be made in a sufficiently large proportion of cases; (2) the correlations with resultant weather are good; and (3) the time lags in associated weather are reasonable in the light of what would be expected from a knowledge of other physical factors, the method offers hope for development of a definite aid to weather forecasting.

While the author uses the isentropic chart as the basis for his computations, he points out that the constant pressure chart could be used in a similar manner. However, the latter would probably require a slightly greater degree of approximation than the isentropic because it would require consideration of the lapse rates, but the constant pressure charts are easier to prepare initially. It is my understanding that **JAMES E. MILLER** of New York University, who was associated with the author, is investigating this possibility.

Computations of the field of vertical motion by **FLEAGLE'S** method, or by other similar methods, probably involve too much work for routine use on forecast stations, but if general use is found desirable or practicable, it would probably necessitate computations being made at one central point and the results transmitted to forecast stations. An alternate but less desirable method would be to have each forecast center make computations for a limited area and the results from each forecast station be transmitted to other offices.

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(See also pp. 338, 357, 378, 388, 392, 414, and 450)

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Transactions, American Geophysical Union Volume 26, Number III December 1945

CORRELATIONS OF SOLAR VARIATION WITH WASHINGTON WEATHER

C. G. Abbot

Temperature and solar activity--Nine years ago I showed that ups and downs in the values of the solar constant of radiation were attended by changes of large magnitude and long duration in the temperature of Washington and other stations. These effects were always symmetrically opposed like the right and left hands. Meteorologists have been reluctant to accept this finding, partly because the solar changes found seemed to them too small to be certainly observed, and partly because no mathematical theory had been worked out to show how small percentage-changes in the solar constant could so largely alter terrestrial temperatures.

Nevertheless, further work convinced me of the reality of the effect and recently I have secured new evidence that seems to clinch it.

Everyone recognizes the validity of the measurements now being made at many stations of what is called "critical frequency" in ionization-layers of our atmosphere. Among them is the quantity called f^{o}_{E}, the E-layer critical frequency. This quantity was observed at all daylight hours and some night hours during the years from 1938 to 1944 by the observatories of the Carnegie Institution of Washington at Huancayo (Peru) and Watheroo (Australia). Dr. FLEMING has generously provided me with copies of these data, which, however, are in the war category "restricted" and therefore unpublished. For my purposes I computed for each day from 1938 to 1944 the mean value of f^{o}_{E} for eleven daylight hours. It is of course very clear that for the most part this quantity is a measure of some kind of solar radiation which travels with the speed of light. For the night values are very low and there is an immediate rise at sunrise and fall at sunset. I am told, too, that f^{o}_{E}-values go nearly to zero during total solar eclipses. These measurements of the Carnegie Institution of Washington seemed well suited to check my earlier results on the correlation of solar variation with temperature-departures.

I made monthly graphs of my daily mean daylight values of f^{o}_{E} for Huancayo and Watheroo (see Fig. 1). The two stations do not fully agree, but they both show nearly simultaneously many rises and falls of the daily values. These changes observed at both stations frequently reach ten per cent or more, whereas the percentage-changes found in the solar constant seldom exceed one per cent.

I found from the seven years available, 1938 to 1944, from 15 to 25 cases of rise and 15 to 25 cases of fall of mean daily f^{o}_{E}-values for each of the 12 months January to December. For each case I wrote a line of the departures of temperature at Washington from five days before to 19 days after the zeroth day, when the solar change seemed to begin. Thus, for each of the 12 months of the year I had a table of 15 to 25 lines, and 25 columns. The mean values of the columns, when plotted, showed the average sequences of temperatures at Washington which are caused by the rise and fall of the solar activity during each month of the year.

These curves were almost exactly the same in phases and amplitudes as the curves obtained similarly from the dates when the solar constant rose and fell in the years 1924 to 1939 (see Fig. 2). The identity is indeed so close that there is no reason to separate the two sets of data, one derived from Smithsonian solar constant work and the other derived from measures of f^{o}_{E} by the Carnegie Institution of Washington. I have now mean curves of Washington temperature-change for each month of the year, derived from the combined data of the years 1924 to 1944, and representing mean effects of rise and of fall in solar activity (see Fig. 3).

Of these curves, each a mean of from 30 to 50 individual cases of solar change, I remark:

(1) Temperatures at other stations show the same sort of correlation with solar activity as does Washington for the same days of solar change, though varying as regards individual features, as would be expected, owing to different local conditions.

(2) At every station, and in nearly every month, the temperatures depart in opposite directions,

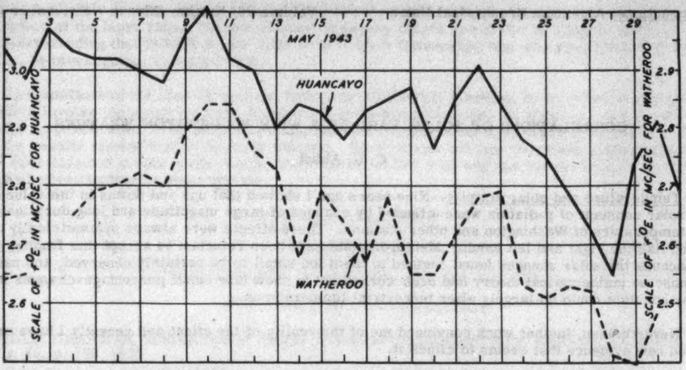

Fig. 1--March of solar ionizing-activity, May 1943
[The two curves are plots of successive daily mean values of E-layer "critical frequencies" from observations of Huancayo (Peru) and Watheroo (Western Australia); each point represents the mean "critical frequency" for the 11 daylight hours 7 to 17]

attending, respectively, rising and falling solar activity. Thus comes about an axial symmetry of the pairs of curves, such for instance as subsists with one's right hand and one's left.

(3) The march of the curves differs from month to month, and differs for the same month from station to station, yet the right and left symmetry nearly always prevails.

(4) The effects are large. Differences of temperature of the order of 10°F, or more, depend on whether a rising or a falling sequence of solar activity preceded them many days before.

(5) The effects of solar changes on temperature persist for many days. They may surely be traced from three days before to 14 days after the zeroth day of the solar sequence.

(6) The coefficient of correlation between curves corresponding to rising and falling solar activity from -3 to +15 days for Washington temperature-data of the month February (a fair sample) is -80 ±5.5 per cent.

(7) Since far-separated cities respond similarly in these respects to the common system of dates given in the tables, this system of dates must have a cosmic significance. The system of dates, in other words, betrays an extraterrestrial selection, harmonious to the claim that on these dates changes in radiation occurred in the Sun.

Precipitation and solar activity--Without much expectation of strong correlations, because of the sporadic character of precipitation, I nevertheless worked out tables of Washington precipitation accompanying the dates of change of solar activity from 1924 to 1944. To my surprise the curves (see Fig. 4) representing the mean results of the tables showed strongly marked features, with symmetrical opposition in precipitation corresponding to rising and falling solar activity.

Prediction of temperatures--From what has gone before it is clear that the Sun's variations are a major factor in weather. The effects produced are large. In Washington temperatures it made over 20°F of difference in some months whether the solar constant rose or fell by 3/4 per cent, a week or more previously. The effects are long continuing. They appear to begin three days before measurable changes in radiation occur, and to last at least 14 days after, making an important sequence of 17 days in weather attending each change of solar radiation.

The question arises whether solar observations may be utilized for prediction of weather. Obviously it would be necessary to have all the dates when solar changes occur. For the effects are so large that to use some and omit others would lead to great error. Furthermore the exact dates

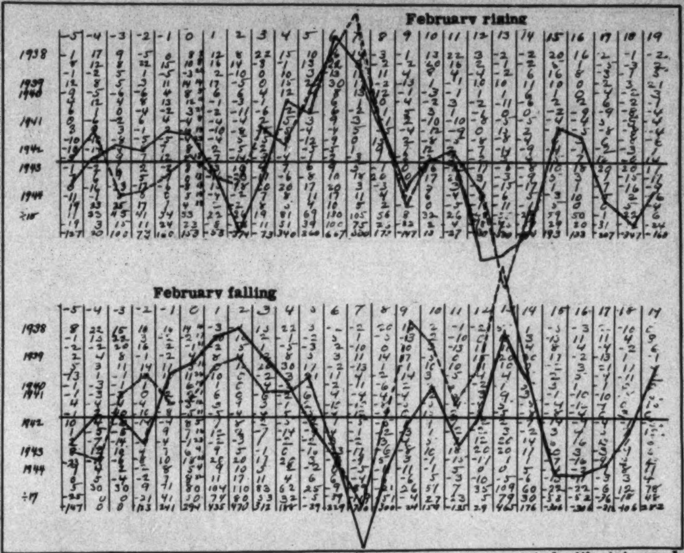

Fig. 2--Mean Washington temperature-sequences of February, associated with rising and falling solar activity

[Full curves, top and bottom, represent mean march of departures from normal Washington temperatures for 15 and 17 cases, respectively, of 25 successive days each; dates marked zero are dates of beginning of rising and of falling sequences of E-layer "critical frequencies," as indicated by combined results of Huancayo (Peru) and Watheroo (Western Australia) for years 1938 to 1944; dotted curves represent mean sequences of Washington departures from normal temperatures associated with zeroth dates of rise and fall of the solar constant of radiation, from Smithsonian observations at Montezuma (Chile) and St. Katherine (Egypt) for years 1924 to 1939]

are necessary, for the effects change rapidly from day to day.

In order to test the prospects with the present available data, I have attempted a solar weather forecast for the temperature at Washington covering the interval January 1 to May 28, 1943, and have compared it with the event. For illustration I present the solar expectation for the interval February 1 to March 14 in Figure 5. The method of computing it is simple. From the records of the E-layer ionization-data, one takes all the dates when ups and downs of solar radiation occur. Opposite each one of these dates he writes in a column of 17 days the departures from normal temperature appropriate to the observed solar change. He then adds the columns algebraically to give in sequence the combined temperature-effect of all of the solar changes.

In Figure 5, I show in dotted lines the departures from normal temperature due to integrated solar effects, and in full lines the actual event. It will be seen that the two curves show the same number of principal peaks and troughs. These fall nearly in the same phases. Their phase-differences in days are as given in Table 1.

Table 1--Phase-differences in days

Maxima	H	I	J	K	L	M	
Phase-differences	+2	+1	+2	-1	0	0	
Minima	A	B	C	D	E	F	G
Phase-differences	+2	+1	-1	0	+1	0	-1

Average phase-change: Regarding sign, +0.47 day, disregarding sign, ±0.91 day

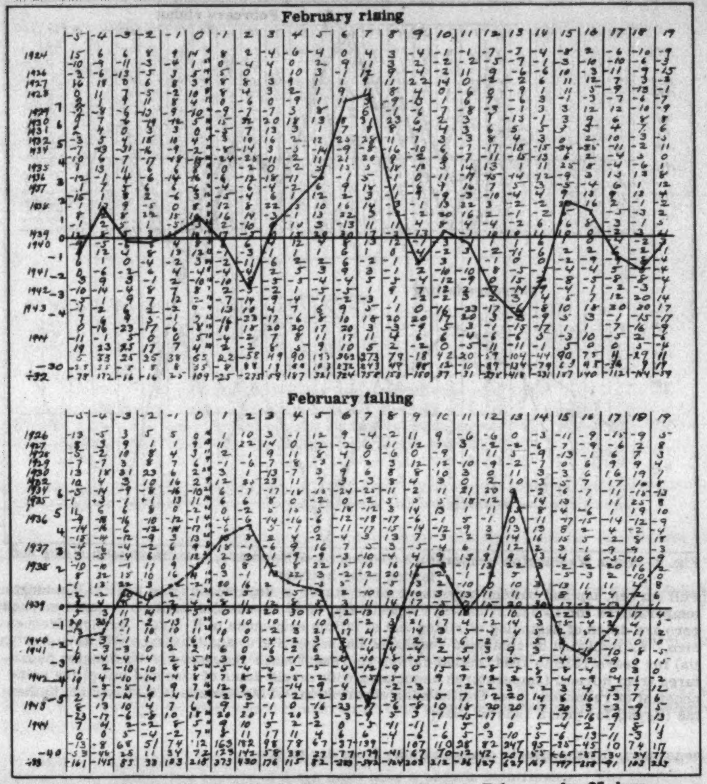

Fig. 3--Mean sequences of Washington temperature in February for 25 days, for years 1924 to 1944

[These curves are similar to those of Fig. 2, but result from combining the mean temperature-sequences associated with solar-constant changes on zeroth day with similar mean sequences associated with changes of E-layer "critical frequency," on zeroth day]

The magnitudes of the actual swings from peaks to troughs exceed those of the solar integration in the ratio 5/4. While the general similarity of the curves is obvious, the differences in phase and in magnitude of swings lead to such wide divergences that the day-to-day correlation-coefficient is small, only 0.09.

I have sought to find a mathematical comparison between the two curves which would take groups of several days as its basis. For this purpose I join points A B C D E F G at the troughs of the dotted curve. At the mid-points of the lines AB, BC, etc., I observe the departures. I then sum up the departures of the several days within each triangle as they would be if measured from horizontal base-lines through these mid-points. I also treat the full curve in the same way, except that their base-lines are determined, not by the trough-points of the full curve, but by the points of the identical dates used with the dotted curve. This procedure yields the comparison given in Table 2.

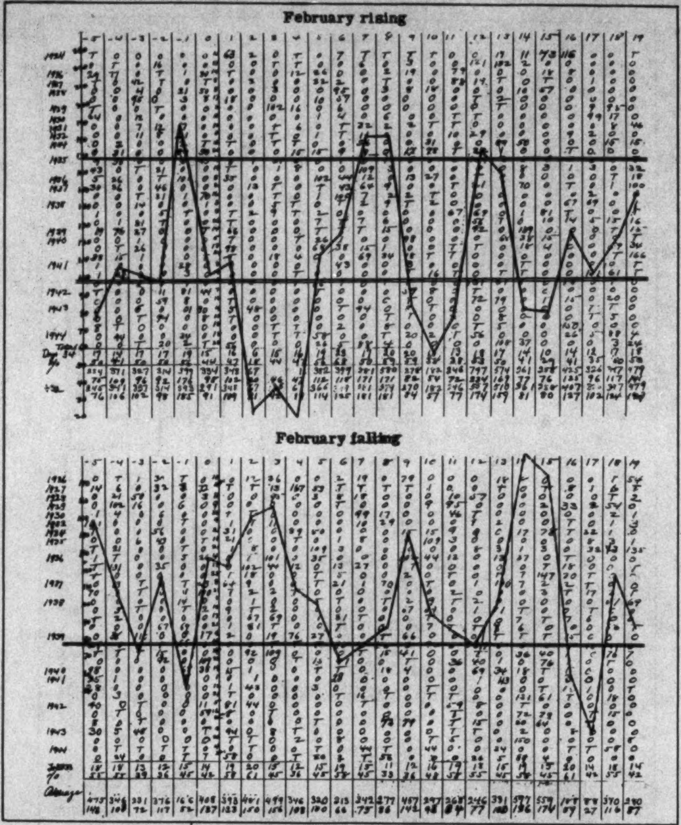

Fig. 4--Mean sequences of Washington precipitation in February for 25 days, for years 1924 to 1944

[These curves are similar to those of Fig. 2, except that they represent mean values of total precipitation instead of mean values of temperature-departures]

Table 2--Comparison of predicted and actual event

Sums	Triangle						Algebraic total
	AHB	BIC	CJD	DKE	ELF	FMG	
(1) Dotted	+33.3	+73.8	+117.7	+37.6	+36.2	+60.5	+359.1
(2) Full	- 7.0	+46.0	+190.0	+43.0	+40.0	+48.5	+360.5

This comparison shows that in all but one of the six cycles of temperature change from low to high and return, which occurred during the intervals from February 1 to March 14, 1943, the solar

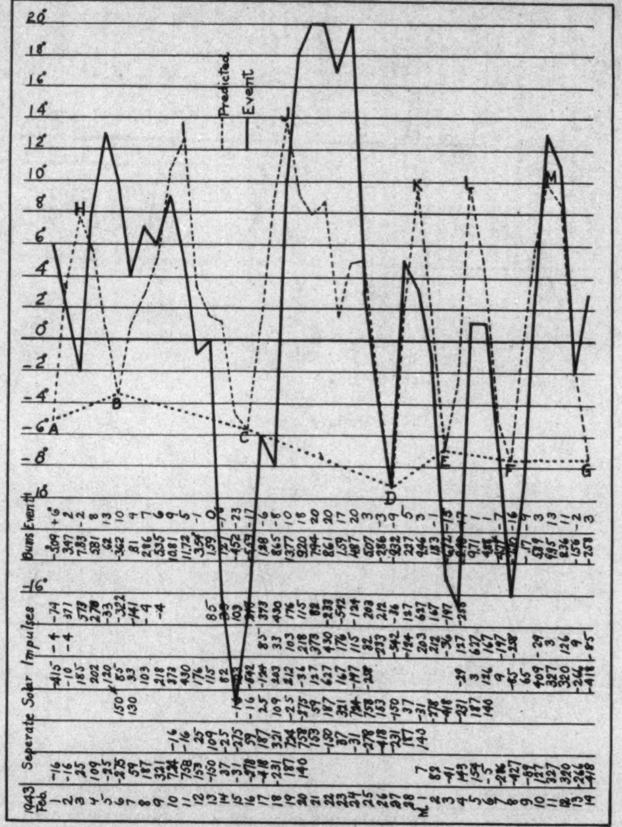

Fig. 5--Integrated effects of changes in solar activity compared to observed temperature-departures

[The dotted curve represents the combined temperature-effects of all observed cases of solar change, as indicated by rise and fall of E-layer "critical frequency," which occurred from January 21, 1943, to March 13, 1943; full curve represents actual observed departures from normal temperature at Washington from February 1 to March 15, 1943]

integration and the actual event were in approximate accord regarding the phases, signs, and magnitudes of the changes. In the one case of disagreement it was caused by the solar integration having anticipated the event by two days.

To determine how far solar predictions, if they were made, could be expected to anticipate the event, I have recourse to the columns used to give the aggregate.

On February 10 the result was almost entirely fixed by the solar rise of February 4 and the solar fall of February 9. Unless the latter could have been anticipated there would have been little range of prediction.

On February 15 the result depended chiefly on the solar fall of February 9 and the solar rise of February 13. Unless the latter could have been anticipated there would again have been little range of prediction.

On February 20 the result depended mainly on the solar rise of February 13. Five other involved solar changes nearly cancelled themselves out.

On February 25 the result depended mainly on the solar rise of February 18. Here, four other involved solar changes nearly cancelled themselves out.

On March 3 the result depended mainly on the solar rise of February 18.

On March 8 the result depended mainly on the solar rise of March 4 and the solar fall of February 20.

It appears from these comparisons that approximate predictions a week in advance could be made of dates of peaks and troughs of Washington temperature (1) if daily reports of f^{o}_{E} were obtained from a sufficient number of ionization-stations, and (2) if means could be found to anticipate by a few days closely the date of the next approaching solar change. Its sign would always be known to be opposite to that last observed. From present records we should expect solar changes of the same sign to follow each other at intervals of about nine days, with changes of opposite sign intervening. But we may hope that means may be found to anticipate more exactly the date of the next approaching solar change by a few days. Its sign and the effect that it will produce upon the temperature when it does occur will always be known. There is, I think, a fair hope that such important dates as heavy frosts may become predictable a week in advance from solar observations.

The method is applicable to any station for which daily records of weather for the past 20 years are available.

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DISCUSSION

J. B. KINCER (4112 Fessenden Street, N. W., Washington 16, D. C., August 4, 1945)--The very great economic importance of studies of this kind which attempt to develop a tool for long-range weather forecasting has been recognized for many years. Dr. ABBOT has done and is doing yeoman work in this field which it is universally hoped may ultimately assist in developing a system useful for such forecasting. He recognizes, however, that much remains to be done before wide-spread application of extraterrestrial phenomena, such as solar radiation, can serve as such a tool with general application to different (especially far-separated) areas.

The lack of synchronous, wide-spread uniformity in weather occurrences, especially precipitation, presents a very formidable and definite challenge to the would-be long-range forecaster. Dr. ABBOT says "Since far-separated cities respond similarly in these respects to the common system of dates given in the tables, the system of dates must have a cosmic significance." We take it that he does not mean to imply that in the "run-of-the-mine" weather, far-separated cities always have comparable, or even fairly comparable, temperature-conditions. Much depends on just what we mean by "far-separated cities." This would never apply to the entire United States, though occasionally very extensive areas do have remarkable uniformity in anomalies for rather extensive periods of time. The period covered in his paper contains at least two such unusual (instead of usual) occurrences. For example, for the five days February 20 to 24, the temperature at Boston, Massachusetts, averaged 18° above normal, Washington, D. C., 19°; Atlanta, Georgia, 13°; and St. Louis, Missouri, 15°. For the opposite phase, average minus departures for the entire week of March 2 to 8 were: Atlanta, Georgia, 13°; New Orleans, Louisiana, 15°; St. Louis, Missouri, 20°; Minneapolis, Minnesota, 19°; Helena, Montana, 20°; and Denver, Colorado, 17°.

However, the wide-spread uniformity here found does not typify usual weather-conditions. Even in the two cases mentioned considerable areas of the country did not conform at all to these pronounced anomalies; in fact, in the first case some areas had below-normal temperatures, while in the second some had above-normal every day for the entire week, as shown in Table 1.

Table 1--Departure of daily mean temperature from normal, February 1 to March 15, 1943

Date	Washington, District of Columbia	Boston, Massachusetts	Atlanta, Georgia	New Orleans, Louisiana	St. Louis, Missouri	Minneapolis, Minnesota	Helena, Montana	Denver, Colorado	Phoenix, Arizona	Pocatello, Idaho	Portland, Oregon	San Francisco, California
1943	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
Feb. 1	+ 6	+ 7	+ 3	+ 6	0	- 7	- 1	+12	+ 7	- 4	+ 2	+ 1
2	+ 2	- 2	0	+ 6	+11	+ 7	+ 6	+13	+ 1	0	+ 6	+ 3
3	- 2	- 2	+ 5	+12	+20	+20	+ 6	+ 3	+ 1	0	+ 4	+ 3
4	+ 8	+ 9	+13	+16	+16	+ 9	+ 9	+ 3	- 1	+ 3	+ 7	+ 1
5	+13	+14	+16	+11	+17	+13	+ 9	+ 3	+ 1	+ 3	+ 5	+ 4
6	+10	+ 7	+ 6	+ 1	+ 5	- 4	+13	+ 9	+ 3	+10	+ 1	+ 3
7	+ 4	+ 9	+ 2	+ 2	+15	+ 4	0	+19	+ 7	+13	- 3	- 1
8	+ 7	+ 3	+12	+ 4	+23	+11	-21	+21	+ 6	+ 3	- 1	- 6
9	+ 6	- 1	+12	+10	+28	+14	-24	- 2	- 6	- 5	- 4	- 5
10	+ 9	- 2	+14	+ 6	+ 8	+ 1	-16	- 7	- 6	- 7	+ 3	- 2
11	+ 5	+13	- 5	-13	- 6	-14	+10	+10	- 2	+ 6	+10	+ 2
12	- 1	- 2	- 1	- 5	- 2	- 7	+13	+ 6	+ 6	+ 6	+ 8	+ 7
13	0	- 1	- 7	- 3	-15	-18	+12	+16	+ 9	+ 9	+ 2	+10
14	-16	- 8	-23	-11	-24	-22	+ 5	+19	+11	+ 4	+ 6	+10
15	-23	-33	-24	-13	-19	-14	0	+ 7	+ 9	+ 1	+ 6	+ 8
16	-17	-27	-19	-11	-17	- 6	+ 3	+13	+10	+ 3	+ 4	+ 8
17	- 6	- 9	- 7	- 4	+ 4	+ 1	0	+14	+ 8	+ 3	+ 6	+ 5
18	- 8	-11	+ 2	0	+ 7	+10	0	+15	+ 6	+ 4	+ 7	+ 7
19	+10	+ 1	+ 8	+ 2	+22	+19	+ 7	+17	+ 9	+ 8	+ 7	+10
20	+18	+18	+11	+ 5	+19	+15	+11	+13	+12	+ 6	+ 4	+ 9
21	+20	+18	+10	+ 6	+ 8	+13	+ 7	+15	+12	+ 5	+ 3	+ 4
22	+20	+17	+13	+ 1	+15	+12	- 3	+16	+ 8	+ 8	+ 4	0
23	+17	+21	+13	+ 3	+18	+ 9	-13	- 5	+ 3	- 1	+ 5	- 1
24	+20	+17	+17	+ 7	+ 3	- 7	- 8	- 8	+ 3	- 2	+ 4	- 1
25	+ 3	- 4	+ 2	+ 6	- 8	- 9	-10	- 5	0	- 1	+ 2	- 3
26	- 3	- 8	- 9	- 4	-10	- 9	-11	- 1	+ 4	+ 3	+ 7	- 1
27	- 9	- 4	-17	-12	+ 4	+ 6	- 4	+ 5	+ 4	+ 1	+ 8	- 2
28	+ 5	+ 6	- 7	- 8	+ 2	- 4	- 1	+ 3	- 1	+ 3	+ 2	+ 1
Mar. 1	+ 3	+ 4	- 4	0	-12	-24	-18	-19	+ 1	- 7	+ 6	+ 3
2	- 1	- 1	- 4	-12	-25	-26	-23	-33	+ 2	-14	+ 5	+ 3
3	-15	-14	-21	-26	-24	-14	-16	-12	+ 4	- 8	+ 5	+ 2
4	-17	-18	-21	-18	- 6	- 6	-17	- 6	+ 3	- 4	+ 3	+ 6
5	+ 1	0	-11	- 1	-12	-19	-27	-30	+ 3	- 4	- 3	+ 2
6	+ 1	+ 5	- 2	- 9	-22	-21	-29	-33	+ 3	-11	- 7	+ 3
7	- 7	- 3	-18	-19	-29	-25	-20	-14	+ 3	- 1	- 2	+ 4
8	-16	-13	-16	-17	-22	-20	- 6	+ 9	+ 5	+ 5	0	+ 4
9	- 9	-17	-10	- 6	0	- 6	-15	0	+ 7	- 4	- 2	+ 7
10	+ 3	+ 2	+ 2	0	0	- 6	-11	-10	+ 8	- 4	- 2	+ 4
11	+13	+15	+ 8	+ 9	- 6	- 1	0	- 1	+ 3	+ 1	- 1	+ 3
12	+11	+15	+ 6	+10	- 2	+ 3	+ 6	+ 6	+ 2	+ 5	+ 2	+ 1
13	- 2	+ 4	+ 6	+ 3	+ 7	+ 6	- 6	+13	+ 5	+ 8	0	0
14	+ 3	+ 7	+ 3	+ 4	+13	+ 4	-27	+15	+ 6	- 1	- 5	- 2
15	+12	+ 7	+ 6	+ 9	+16	- 1	-26	- 5	+ 3	- 9	- 3	- 4

Careful examination of Table 1, covering the period used by Dr. ABBOT in his Figure 5, for Washington, D. C., discloses that conformity in anomalies is more or less in inverse relationship to the distance between stations. Twelve stations distributed to represent fairly all sections of the country are included in Table 1 which shows daily temperature departures for each station, for the period February 1 to March 15, 1943. The diminishing conformity with increase in distance between stations, and, finally, the entire disappearance of relationships are shown by a series of correlations between Washington as a base and the other stations contained in the Table. The coefficients, in each case with the station named, are as follows: Boston, +0.91; Atlanta, +0.87; New Orleans, +0.69; St. Louis, +0.61; Minneapolis, +0.43; Helena, +0.04; Denver, +0.06; Phoenix, +0.01; Pocatello, +0.12; Portland, ±0.00; and San Francisco, -0.23. It will be noted that the entire western half of the country shows no appreciable overall relationship with Washington.

Another interesting comparison illustrating the diminishing relationships with increasing distances between stations may be made from Table 1 as follows: With Denver as a focal- or reference-point, we find, westward, a correlation-coefficient with Pocatello of +0.79, and with Portland, farther west, +0.31. To the eastward, the correlation-coefficient with St. Louis is +0.43 and with Washington +0.06. This all has a direct bearing on the question as to how effectively a formula, or other device, based on extraterrestrial phenomena, for a single section (or specific, limited area) could have general application for forecasting purposes. Precipitation is even much more erratic (see lower half of Fig. 1).

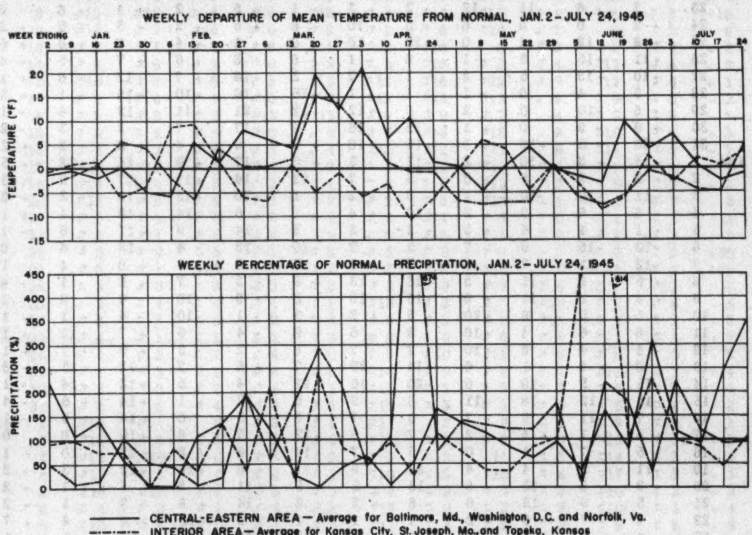

Fig. 1--Weekly departure of mean temperature from normal and weekly percentage of normal precipitation, for Central-Eastern, Interior, and Central-Western areas of the United States, January 2 to July 24, 1945

In considering probable relationships between two sets of data as disclosed by correlations of this kind, it should be remembered that, with an adequate number of pairs of data, the relative significance of the coefficients is proportional to their squares, so that a coefficient of 0.80, say, would be four times as significant as one of 0.40.

Table 2--Departure of daily mean temperature from normal, March 16 to April 30, 1943

Date	Washington, District of Columbia	Boston, Massachusetts	Atlanta, Georgia	New Orleans, Louisiana	St. Louis, Missouri	Minneapolis, Minnesota	Helena, Montana	Denver, Colorado	Phoenix, Arizona	Pocatello, Idaho	Portland, Oregon	San Francisco, California
1943	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
Mar. 16	+22	-2	+13	+9	0	-11	-30	-8	-3	-10	-3	0
17	+13	-2	0	-7	+2	-22	-28	-14	-1	-9	-3	-5
18	+9	+14	-2	+7	-6	-14	-31	-21	+1	-12	-7	-1
19	+22	+4	+11	+15	-7	-16	-15	-12	-5	-10	-1	0
20	+12	+3	+1	-2	-14	-13	-15	-11	-3	-13	-1	+2
21	-6	0	-9	-9	-10	-14	-13	-7	-2	-6	+1	0
22	-8	-5	-16	-12	-11	-12	-8	+5	+1	+1	+2	0
23	-7	-6	-11	-12	-2	+3	-1	+5	-2	+1	+6	0
24	+2	0	0	-6	+5	+10	+8	+5	+2	+5	+5	+2
25	+9	+12	+4	0	+10	+16	+8	+6	+4	+7	+6	+6
26	+11	+15	+5	-1	+8	-1	-6	+8	+6	+7	+5	+4
27	+10	+13	+5	-2	-1	-7	+3	+14	+7	+12	+6	+1
28	-3	-4	0	+1	-1	-1	+15	+16	+10	+15	+1	+2
29	-8	-10	0	+2	+6	+12	+12	+21	+11	+13	-4	-1
30	+9	-9	0	+1	+19	+26	0	+17	+7	-3	-3	-2
31	+20	-5	+10	+3	+16	+10	+5	+6	+4	+2	+2	+2
Apr. 1	+14	+3	+10	+2	+12	-3	+6	+17	+9	+14	+12	+5
2	+2	+9	+5	+8	-5	-7	+13	+14	+11	+17	+2	+3
3	-11	-10	-10	+1	-9	+2	+1	+20	+12	+10	-2	+3
4	-8	-6	-3	+2	+10	+4	-1	+6	+14	+10	+4	+1
5	+1	+1	+4	+5	+2	-3	+3	+14	+9	+11	+6	-1
6	-12	-15	0	+7	-2	+2	+10	+13	-4	+13	+4	0
7	-12	-11	+7	+5	+7	+8	+7	+5	-6	+8	+4	-1
8	+5	-8	+11	+8	+16	+13	+9	+3	-7	+6	-1	-4
9	+4	-2	+11	+9	+16	+13	+3	+3	-10	-6	0	-2
10	-1	-5	+9	+10	+5	+2	-3	-1	-10	-4	+1	+1
11	-8	-6	+4	+10	-3	-6	+9	-4	-6	+7	+12	+1
12	-1	-4	+8	+10	-2	-7	+8	+2	-2	+9	+17	+1
13	0	+4	-1	+6	-14	-20	+7	+5	+2	+11	+15	-3
14	-15	-5	-19	-6	-20	-16	+11	+4	+5	+12	+14	-1
15	-15	-12	-18	-11	-8	-9	+5	+12	+1	+14	+6	-4
16	-7	-11	-6	-7	0	-7	+8	+5	0	+14	+5	-1
17	+4	-1	+4	-2	-7	-6	+12	+7	+6	+10	+8	0
18	-5	-7	-1	0	-5	-7	+14	+6	+8	+13	+10	+1
19	-11	-8	-4	-4	-20	-9	+11	+6	+10	+12	+3	+2
20	-3	-8	-12	-6	-13	-5	+9	+11	+8	+1	+1	+2
21	-5	-9	-13	-6	-6	+2	+2	+14	+8	+3	-1	+2
22	-4	-7	-6	-2	-7	-1	+1	+9	+10	+4	-4	+7
23	-4	+3	-9	+3	+1	+2	+10	+14	+12	+14	-1	+1
24	0	+8	-8	0	+4	+12	-1	+16	+13	+5	-1	-1
25	+8	+12	-2	-1	0	+3	-10	+6	+10	0	-3	-3
26	+9	+7	+7	+1	+6	-1	-11	+10	+5	-5	-2	-2
27	+5	-3	+8	+3	+9	-8	-8	+2	+7	0	+3	-1
28	+6	+3	+9	+5	-3	-3	-7	+14	+8	+5	+1	+2
29	-4	+1	+6	+8	+7	0	-6	+11	+10	+4	0	+2
30	+6	-4	+8	+8	+1	-10	0	+3	+12	+12	0	+6

Table 3--Departure of daily mean temperature from normal, May 1 to June 15, 1943

Date		Washington, District of Columbia	Boston, Massachusetts	Atlanta, Georgia	New Orleans, Louisiana	St. Louis, Missouri	Minneapolis, Minnesota	Helena, Montana	Denver, Colorado	Phoenix, Arizona	Pocatello, Idaho	Portland, Oregon	San Francisco, California
1943		°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
May	1	- 9	- 6	- 5	+ 8	-10	- 7	0	+16	+13	+ 6	+ 3	+ 6
	2	-10	- 4	- 2	+ 8	+ 6	- 3	0	+11	+13	+ 5	+ 2	+10
	3	+ 8	- 4	+ 7	+ 8	- 3	- 1	+ 7	+10	+13	+ 8	+ 5	- 2
	4	- 5	- 3	+ 1	+ 7	- 3	+ 4	+ 1	+ 8	+ 6	+ 4	- 4	- 1
	5	- 2	+ 1	+ 1	+ 7	+10	+16	- 3	+ 5	+ 4	- 5	- 6	+ 2
	6	+10	+ 3	+ 6	+ 7	+ 8	- 5	- 3	- 9	+ 7	- 5	- 1	+ 4
	7	+15	+ 8	+ 5	+ 5	- 6	-14	- 7	- 9	+ 6	-10	- 1	+ 8
	8	+15	+12	+ 4	+ 6	-13	- 8	- 4	-18	+ 1	- 6	+ 3	+16
	9	+ 8	+ 7	+ 4	+ 6	- 9	- 1	0	-14	+ 1	- 4	- 2	+ 8
	10	+ 8	- 1	+ 7	+ 6	- 1	- 1	-10	0	+ 3	- 2	- 4	+ 3
	11	+ 6	- 6	+ 1	0	- 8	- 8	-18	+ 2	+ 4	-12	- 4	+ 3
	12	+10	- 6	- 5	+ 3	- 2	-13	-16	-22	+ 7	-12	- 6	+ 1
	13	+ 5	+ 6	+ 1	+ 5	- 8	-13	-14	-13	+ 8	- 9	- 6	- 2
	14	- 5	- 3	+ 8	+ 3	-12	- 5	- 9	- 2	+ 4	- 9	- 5	- 5
	15	- 9	- 5	+ 4	+ 2	+ 3	- 7	-13	-12	- 5	-16	- 4	- 5
	16	+ 3	- 2	+ 4	+ 5	+ 4	-12	-12	-12	- 6	-14	- 3	- 1
	17	+10	+13	+ 4	+ 4	- 2	- 7	-10	-17	- 9	- 8	- 1	+ 1
	18	+14	+10	+ 3	+ 3	- 1	0	- 6	-19	- 5	- 8	+ 3	+ 3
	19	+13	+ 2	+ 5	+ 4	- 2	+ 2	- 1	-13	- 2	- 1	+ 7	- 3
	20	+ 9	- 4	+ 6	+ 6	- 8	+ 6	+ 1	- 4	0	+ 1	+ 1	- 1
	21	+ 2	-11	+ 2	+ 6	- 9	+ 5	+ 5	- 6	+ 2	+ 2	+ 2	+ 3
	22	- 2	- 9	- 6	+ 1	- 2	+ 6	+ 3	- 1	+ 2	+ 2	+ 5	+20
	23	- 5	- 1	-10	+ 1	- 2	+ 2	- 5	- 4	+ 6	+ 7	+ 4	+15
	24	- 3	+ 8	- 8	+ 3	- 5	- 8	0	- 7	+ 8	+ 1	+12	- 2
	25	+ 2	+ 4	- 4	- 1	- 8	-13	+ 2	- 3	+10	+ 4	+ 6	- 4
	26	+ 6	- 2	- 5	- 2	- 2	- 9	+ 3	- 2	+10	+ 2	- 1	- 2
	27	+ 4	+ 1	- 1	+ 2	- 3	- 6	+ 8	+ 5	+ 8	+11	- 1	- 5
	28	+ 1	+ 6	+ 1	+ 4	0	+ 5	+10	+12	+ 6	+ 9	0	- 5
	29	- 1	+ 3	- 1	+ 6	+ 5	+14	+ 6	+ 5	+ 7	+11	- 3	- 4
	30	+ 2	0	+ 2	+ 4	+ 1	+11	+ 3	+ 5	+ 3	0	- 5	- 2
	31	+ 6	0	+ 4	+ 4	+ 5	+10	- 3	+ 3	+ 1	- 6	- 4	- 2
June	1	+10	+ 1	+ 6	+ 3	+ 8	+11	- 3	0	+ 2	- 9	- 7	- 1
	2	+13	+ 9	+ 5	+ 3	+ 8	+11	-18	- 6	0	-18	- 6	- 2
	3	+13	+20	+ 6	+ 3	+ 9	+ 9	-18	-11	- 3	-14	- 2	- 2
	4	+15	+ 5	+ 7	+ 5	+ 1	-10	-15	-13	- 8	-17	+ 3	- 1
	5	+14	+12	+ 8	+ 5	+ 3	- 7	- 9	- 7	- 5	-10	+ 2	- 2
	6	+ 4	+ 3	+ 9	+ 4	+ 3	-14	- 9	- 3	- 2	-10	+ 3	- 4
	7	+10	- 6	+ 9	+ 4	- 5	-11	- 3	- 5	0	- 5	+ 5	- 5
	8	+ 1	- 2	+ 4	+ 4	- 6	- 5	- 3	+ 2	+ 2	+ 2	+ 7	- 6
	9	- 7	- 1	+ 3	+ 4	- 4	- 4	+ 1	+ 2	- 1	+ 4	+ 1	- 5
	10	- 5	+ 1	+ 3	+ 3	0	- 2	+ 4	+ 4	- 1	- 1	- 5	- 6
	11	+ 4	+ 3	+ 2	+ 3	+ 4	+ 4	0	- 2	- 2	- 3	- 6	- 4
	12	+ 4	- 2	+ 6	+ 1	+ 9	+ 4	- 7	+ 1	- 8	- 5	- 8	- 5
	13	+11	+ 7	+ 4	+ 2	+ 7	+ 5	- 4	- 2	- 7	- 7	- 6	- 4
	14	+ 9	+ 1	+ 8	+ 3	+ 7	+ 5	- 2	- 3	- 8	-10	- 4	- 5
	15	+ 6	+ 4	+ 8	+ 3	+ 3	+ 6	- 5	- 4	- 5	-10	+ 1	+ 3

Tables 2 and 3 contain data similar to those in Table 1 for the two immediate succeeding periods of a month and a half. These illustrate the irregularities of the temperature-patterns that occur from period to period which would obviously complicate the adaption of any formula for widespread use derived by using records for any single station. The lack of agreement with the data in Table 1 on a station-to-station comparative basis is readily apparent. For example, the correlation-coefficient between Washington and St. Louis falls from +0.61, which might be considered significant, in Table 1, to the insignificant figure of +0.04 in Table 3.

Additional indications regarding the areal comparability of the general run of weather are shown in Figure 1. Here three areas are included instead of data at a single station, to avoid as far as possible local influences. The Central Eastern is represented by the mean temperature of Boston, Washington, and Norfolk, the Interior by Kansas City, Missouri, St. Joseph, Missouri, and Topeka, Kansas, and the Far Western by Modena, Utah, Salt Lake City, Utah, and Ely, Nevada.

For each area there are shown the weekly departures of temperature and the percentage of normal rainfall for each week of 1945 from that ending January 2 to that ending July 24. The correlation-coefficients for temperature (on this weekly basis) are as follows: Central Eastern with Interior, +0.52; Central Eastern with Far Western, -0.44; Interior with Far Western, -0.004.

From the foregoing it appears obvious that before a formula for long-range forecasting of weather based on weather-records for a single station (or a limited area) would be possible for general application, much work remains to be done. This Dr. ABBOT realizes as well as anyone else. However, probably his findings may be useful in the final development of a tool, which it is hoped may be realized eventually, that will provide means for reasonably successful predictions of future weather.

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ADDITIONAL DATA ON THE SPONTANEOUS INCREASE OF MAGNETIC MOMENT

J. H. Nelson and J. B. Campbell

In his paper "On spontaneous increase of magnetic moments" [see 1 of "References" at end of paper], H. H. HOWE included some curves and observations submitted by one of the present authors relating to the increase of moment of magnet 31L, the cobalt-steel long magnet of the Cooke-type magnetometer that has been in use at the Tucson Magnetic Observatory since late 1940. One of the curves showed the variation of the moment of the magnet (corrected to 20°C) with time, over a period of two years. Another showed the variation of the "adjusted" moment, with time, the adjustment being made by eliminating the linear drift of the moment for the two-year period in order to illustrate the seasonal change of the moment. It was demonstrated that the residual seasonal change of the moment was not a direct function of the seasonal temperatures, but was apparently related in some way to those temperatures.

It will be noted in the curve of "Log M_{20} (adjusted)" in Figure 2 of HOWE'S paper that the seasonal range of the adjusted moment during the second year of the data then available was less than during the first year, both the maximum and minimum values being closer to the yearly mean for the adjusted moment. In the light of two additional years of accumulated data, this reduction in range of the adjusted moment is a real one and not a phenomenon resulting from paucity of data at the time HOWE prepared his paper. The two additional years of data have enabled the writers to venture a prediction that the magnetic moment of magnet 31L will have ceased to increase within the next two or three years.

In Figure 1 curve A is the smoothed curve of log M_{20} plotted against time for the four-year interval. The individual monthly means of log M_{20} are also shown to enable the reader to evaluate the degree of smoothing that was adopted. It is apparent from this curve that the annual increase of the observed moment is progressively smaller. It therefore seems appropriate to adopt a progressively decreasing annual correction to eliminate the yearly increase of moment and show only the seasonal variation. Five points were chosen at the relatively flat parts of curve A, and from these were derived graphically the points that describe curve B. The ordinates of curve B were scaled and added to the corresponding ordinates of curve A. The result, curve C, has two interesting indications:

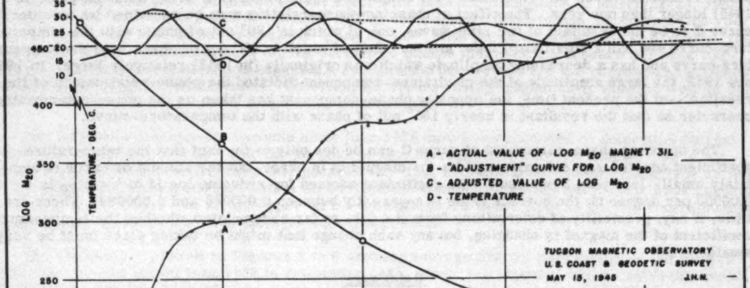

Fig. 1--Observed and adjusted graphs for magnetic moment, magnet 31L

(1) The axis of curve C is, within the limits of graphical error, a straight line. This would indicate that the choice of points defining curve B was reasonable and proper and that the annual increase of the moment will eventually reduce to zero. Another indication of the validity of a curved line of annual decrease of the rate of change of log M_{20} may be seen by an inspection of Figure 1 of HOWE'S paper. It will be seen that the few values of log M_{20} measured early in 1939, before the magnetometer was shipped to Tucson, lie well below the value that would be required by a constant slope of the line of average annual increase for the two years 1941 and 1942. In other words, the increase of moment between early 1939 and late 1940 was definitely greater than the increase during 1941 and 1942. Unfortunately, there is no information about the temperature-cycles to which the magnet was subjected during the period when the magnetometer was not being used (1939 and 1940), though it is believed that the daily and annual temperature-ranges were less than they have been at Tucson.

(2) The envelope of curve C is, again within the limits of graphical error, a pair of straight lines that intersect each other on the axis of the curve at an abscissa corresponding to January, 1947. No attempt has been made to show, graphically or otherwise, whether the intersection of the envelope-lines at January, 1947 is the same point in time at which curve B either reaches a minimum and acquires a positive slope or becomes for all practical purposes a horizontal line. HOWE has made a preliminary examination of the current data, with the idea of subjecting it to a stricter mathematical analysis to determine the nature of curve B. His examination consisted of testing the curve for its approximation to a parabola and to an exponential curve. Neither curve fitted very well, but the authors believe that the exponential curve is the closer approximation for the reason that the misfit between curve B and an exponential curve occurs at the beginning of 1941 where the true path of curve A (and therefore curve B, also) is questionable. The misfit between curve B and a parabola seems to occur near the end of the curves (1944) where there is apparently less chance of error in locating the determining points.

The monthly mean temperatures used in this study are the average of all temperatures at which values of log M_{20} were observed during the month. The usual practice in measuring log M_{20} for the entire four-year period, was to make four groups of observations (two before noon and two after noon) on one day of each week. Ordinarily the afternoon temperature, the year around, was some 10° to 15° C higher than the morning temperature. The extreme temperatures at which observations were made during each year were approximately +5°C for the minimum and +40°C for the maximum. Each group of observations was a measurement of the horizontal component of the Earth's magnetic field, which incidentally gave a value for log M_{20}. The measurement involved the timing of ten overlapping groups of 100 mechanical oscillations of the long magnet (31L) and the measurement of eight deflections of a second magnet by the long magnet, half of the deflections being made at each of two deflection-distances.

An examination of the temperature-curve, D, and its relation to the adjusted log M_{20} suggests the investigation of the temperature-coefficient of magnet 31L. There is unquestionably a changing phase-relation between curves C and D, the length of a cycle of curve C being (at least prior to 1945) longer than one year. The effect of changing phase-relation may be explained by considering curve C to be the resultant of two sine-waves, one of which is 180° out of phase with the temperature-curve and has a small amplitude, and the other of which is 90° out of phase with the temperature-curve and has a decreasing amplitude which was originally (in 1941) relatively large. In 1941 and 1942, the large amplitude of the quadrature-component dictated the phase-relationship of the resultant--at the present time, the opposing phase-component has taken on the phase-determining character so that the resultant is nearly 180° out of phase with the temperature-curve.

The opposing phase-component of curve C can be due only to the fact that the temperature-coefficient adopted several years ago for the magnet is in error, but the amount of error is certainly small--less than 3 per cent. The coefficient adopted for reducing log M to log M_{20} is 0.00008 per degree C; the correct value is apparently between 0.000080 and 0.000082. There is little, if any, possibility of determining from the data so far accumulated whether the temperature-coefficient of the magnet is changing, but any such change that might be taking place must be very small.

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Transactions, American Geophysical Union Volume 26 Number III December 1945

SPORADIC E-REGION IONIZATION AT WATHEROO MAGNETIC OBSERVATORY

H. W. Wells

Abstract--Characteristics of sporadic E-region ionization (Es) at the Watheroo Magnetic Observatory, Watheroo, Western Australia, have been determined from continuous ionospheric recordings since June, 1938. Average diurnal curves show prevalence at night with maximum occurrence near midnight local time. The seasonal features of Es already established for the Northern Hemisphere have been confirmed for the Southern Hemisphere with maximum occurrence of Es in local summer months. Annual trends show increasing values for the period 1938 to 1941 suggestive of an inverse relationship with solar activity. Tests for recurrence-tendencies of Es with the 27-day solar-rotation period have not produced any positive correlation.

Detailed characteristics of the ionosphere have been recorded at the Watheroo Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, since the installation in 1938 of automatic multifrequency equipment. The recorder sweeps over a frequency-range, 0.5 to 16.0 Mc/sec and photographically records apparent heights of the reflecting regions as determined by the time-delay between signal and echo. Certain analyses and the basic data have been published through 1941. Since 1942 the results have been classified by the Armed Services, and have not been available for public use or discussion.

One feature of the ionosphere which continues to arouse considerable interest is sporadic E-region ionization. This condition seems to be caused by clouds or patches of dense ionization which are highly reflecting to the exploring radio wave and produce a number of multiple echoes--that is, signals which bounce back and forth many times between Earth and ionosphere. Some characteristics of sporadic-E are illustrated in Figure 1, which shows a blanketing condition masking the normal F_1-and F_2-regions up to the F_2-region critical frequencies. At times these echoes are so dense that higher ionospheric regions are completely screened from view. At other times sporadic E (henceforth designated Es) is partially transparent and reveals the higher layers through the screen of Es. In the case of Figure 1 the stratum of abnormal ionization developed at a height just above the normal E-layer, and the slight cusp at 3.3 Mc/sec indicates transition from the E-to the Es-layer.

Several occurrences of Es are illustrated in Figure 2, which compares ionospheric records during the magnetic storm of March 24-25, 1940, with quiet-day conditions of March 22-23, 1940. Es occurred in varying degrees of intensity during the magnetic disturbance, as shown in the records of March 25, 1940, at 00^h00^m, 02^h00^m, and 05^h00^m, with the most intense Es at 02^h00^m. This tendency of Es to occur frequently during periods of intense magnetic disturbance has been confirmed by other observations and suggests a relationship between Es and the corpuscular streams producing the magnetic disturbance. However, Es occurs during magnetically quiet as well as disturbed conditions so there is no unique relationship involved.

The Watheroo ionospheric records since June, 1938, have been examined to determine diurnal and seasonal variation of Es. For the purpose of this investigation, only the intense type of Es giving several multiple reflections was considered. This included Es of the blanketing type as well as the partially transparent type with a high reflection-coefficient but did not include weak abnormal-E echoes of the border- or fringe-type. In the tabulations the upper limit of Es was determined by the frequency at which the first multiple-echo disappeared.

The results are plotted in Figures 3 to 6 showing average diurnal distribution in per cent of total time for the period June, 1938, to December, 1941. From the legend it will be noted that solid black represents Es of ten Mc/sec or greater, shaded areas represent Es of five Mc/sec or more, and the unshaded areas show occurrence of intensity, three Mc/sec or more. In terms of oblique-incidence radio-wave propagation, the legend also indicates maximum usable frequency (MUF) at 1000 miles distance corresponding to the vertical-incidence ionospheric measurements. Data for each month are plotted for the 24-hour period beginning at noon 120° East Meridian mean time, thereby clearly demonstrating the general prevalence of Es during night hours with maximum

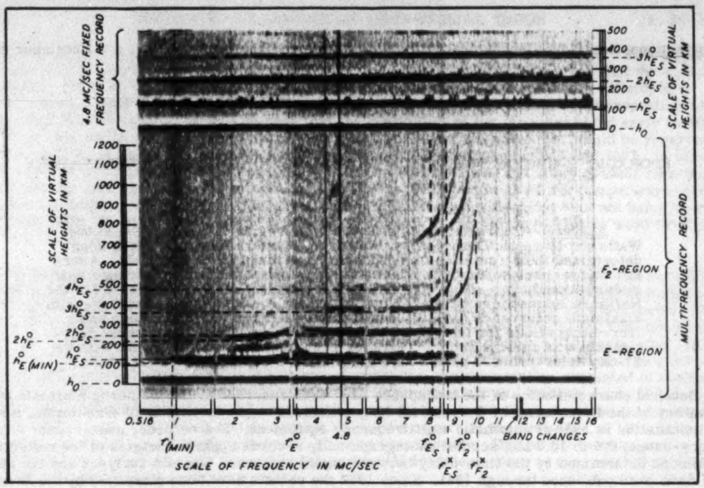

Fig. 1--Ionospheric characteristics from multifrequency records showing sporadic E-region ionization, Watheroo $08^{h}\ 45^{m}$, January 22, 1939

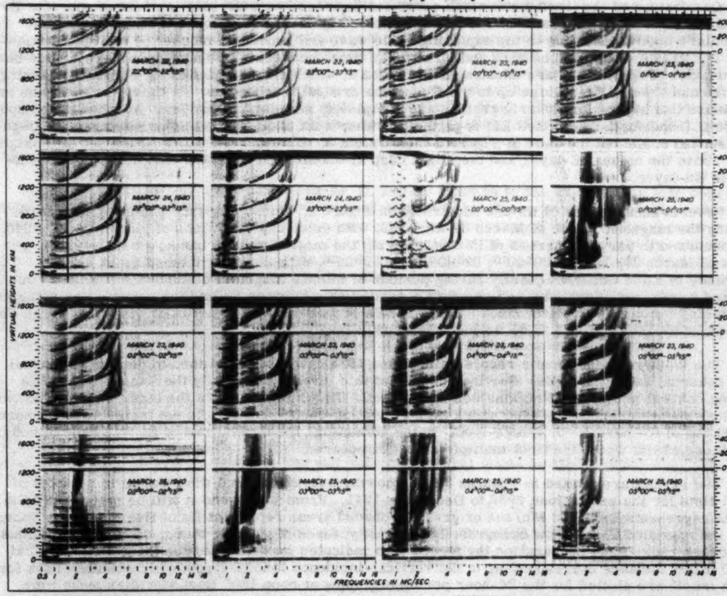

Fig. 2--Records comparing ionospheric disturbance at Watheroo Magnetic Observatory during magnetic storm of March 24-25, 1940, with quiet-day conditions of March 22-23, 1940

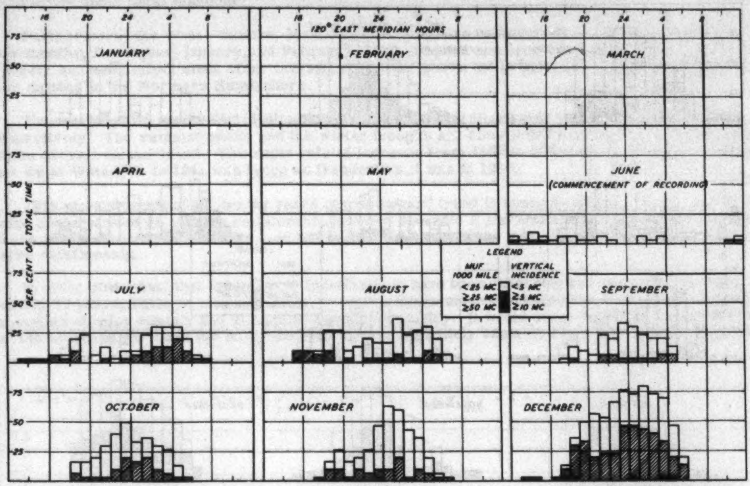

Fig. 3--Diurnal distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1938

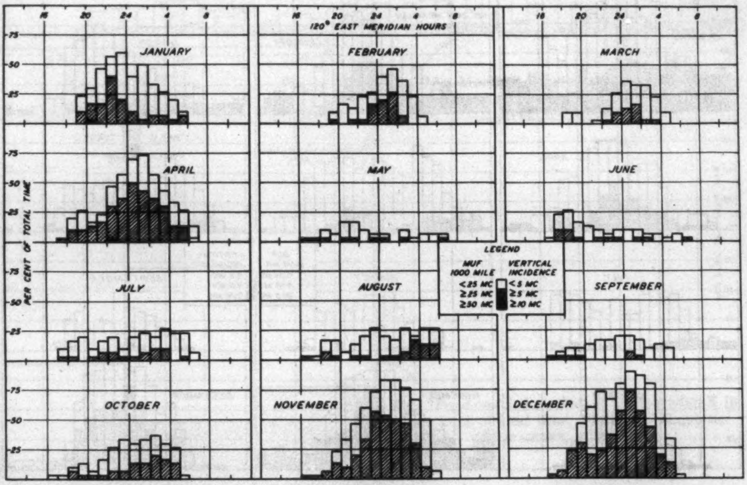

Fig. 4--Diurnal distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1939

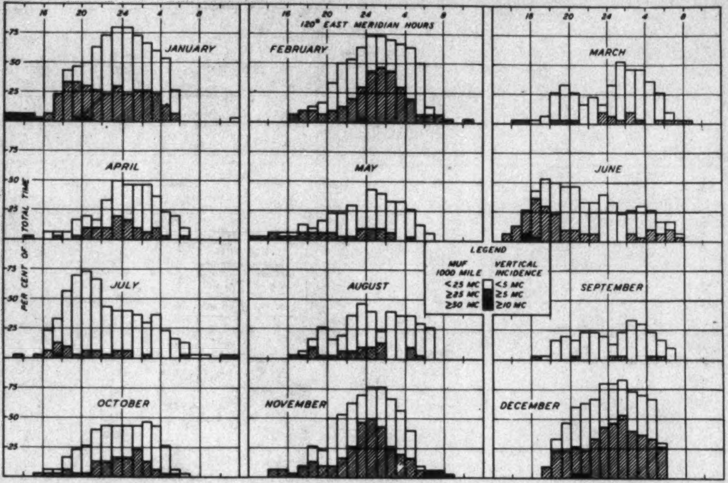

Fig. 5--Diurnal distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1940

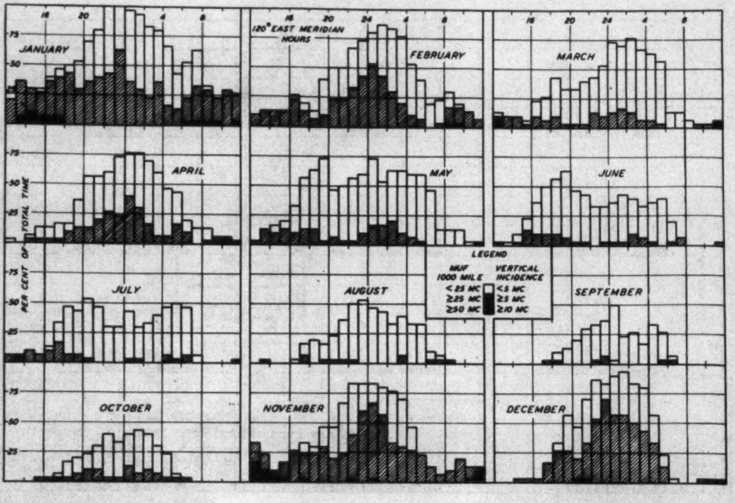

Fig. 6--Diurnal distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1941 occurrence about local midnight.

Furthermore, the winter months, May, June, and July, are relatively free of Es, while the summer months, December, January,and February, show frequent and persistent occurrence. This is a purely seasonal effect since other investigators have shown the predominance of Es during summer months in the Northern Hemisphere.

The monthly and annual distributions are more distinctly illustrated in Figures 7A and 7B, respectively. The summer peaks and the winter troughs are clearly defined although superimposed on the overall annual trend. The rapid rate of increase from 1939 to 1941 is surprising and indicates that Es at Watheroo in 1941 was twice as frequent as it was in 1939.

This upward trend of Es during years of a downward trend in sunspot-numbers might lead to some conjecture of an inverse relationship between sporadic E and annual average sunspot-numbers. These few years of data, however, are not considered as anything more than suggestive of an inverse relationship.

In spite of the fact that ionospheric investigators have been observing and recording Es for a number of years, little is known of its true origin. Radio measurements show that clouds of intense ionization develop rapidly and disappear equally as quickly. It would seem logical to look to the Sun for the origin of Es since the solar ionizing agency adequately explains other ionospheric properties

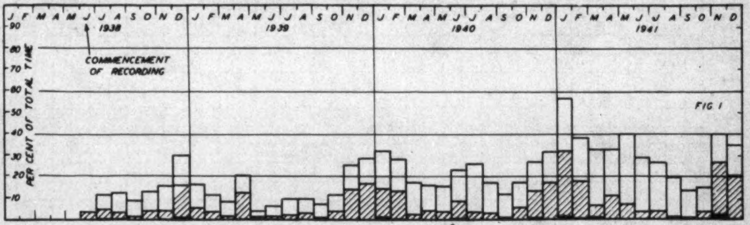

Fig. 7A--Monthly distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1938-1941

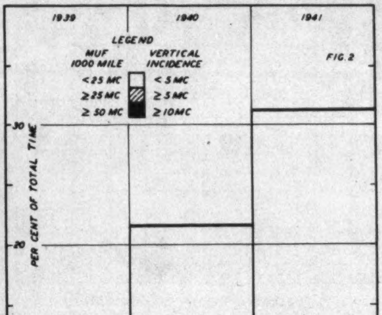

Fig. 7B--Annual distribution of sporadic-E in per cent of total time, Watheroo Magnetic Observatory, 1939-1941

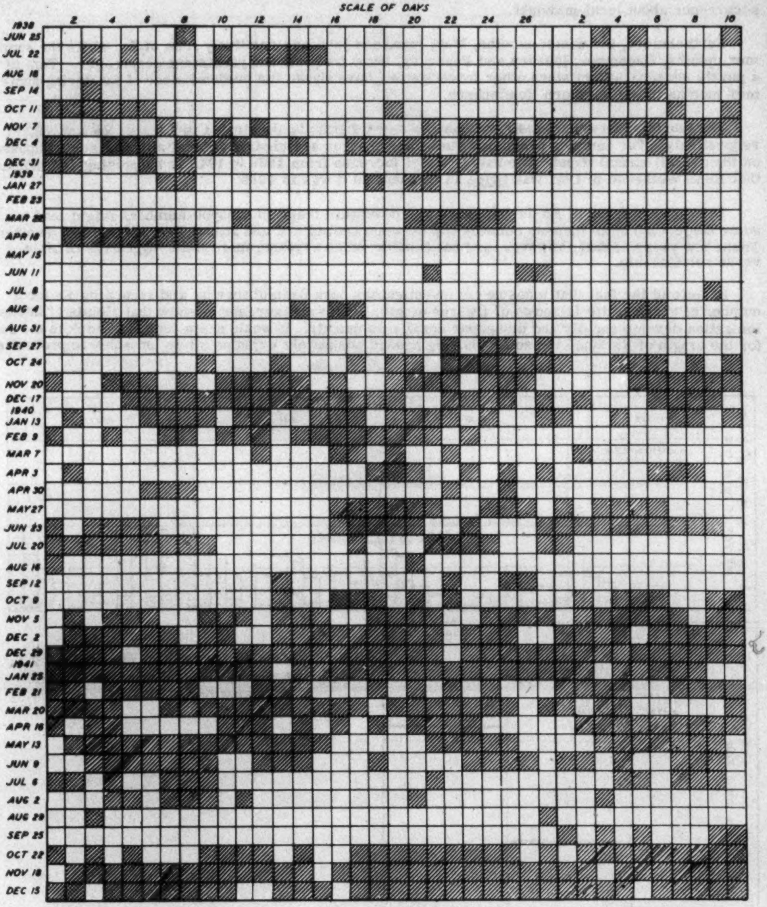

Fig. 8--Test for 27-day recurrence of sporadic-E, Watheroo Magnetic Observatory

as the result of ultra-violet or corpuscular radiation. Obviously, Es is not caused by ultraviolet radiation since it is often prevalent at night as just demonstrated for Watheroo. This would leave corpuscular radiation as the other significant potential solar source. However, the effects of corpuscular radiation alone do not adequately explain the definite seasonal trends since the Southern Hemisphere has a maximum occurrence of Es when the Northern Hemisphere has a minimum, and vice versa.

A preliminary test was made for 27-day recurrence of Es which, if found, would indicate a persistent solar source of these disturbances. The results are shown in Figure 8. Shaded squares indicate days when sporadic-E was greater than the mean for the whole period. In this diagram, recurrent activity at 27-day solar-rotation intervals falls directly below the value for the preceding rotation. Any isolated group of blocks suggests solar recurrence, and the number of vertical blocks in any group shows the number of solar rotations during which the effect persisted. Again we see that seasonal characteristics are emphasized with maximum occurrence in local summer months, but there are no clearly defined recurrences of Es associated with solar rotation. These data have been compared with magnetic activity for the same period which included some recurrent magnetic disturbances as well as isolated storms but nothing conclusive or even suggestive of a correlation has been identified as yet.

Other tests for 27-day recurrence have subsequently been made using the mean value for each solar rotation as reference-point instead of mean value for the period. This eliminates the seasonal effects but still does not reveal any significant evidence of recurrence-tendencies.

The above comments are not intended to discount the probability of Es being caused by some form of solar radiation. It is apparent, however, that studies of Es have many interesting ramifications and that there is much to learn about this phenomenon, which is assuming increased importance in theoretical discussions and in the practical application of ionospheric data to radio-wave propagation.

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NOTES AND PERSONALIA

(See also pp. 351, 388, 390, 429, 430, 440, 444, 455, 456, 458, 459, 460, and 462)

NOTES

Fellowships awarded by the National Research Council--The National Research Council has announced that it is now receiving nominations and applications for predoctoral fellowships in the mathematical, physical, and biological sciences, to be awarded under a grant from the Rockefeller Foundation. The purpose of these fellowships is to assist young men and women, whose graduate study was prevented or interrupted by the War, to complete their work for the doctorate and thus accelerate the recovery of the scientific vigor and competence of the country, seriously set back by the War. The annual stipend will be $1200 for single persons and $1800 for married men with the expectation that eleven months of the year will be spent on academic work. There will be an additional allowance for tuition and fees. Fellowships granted to individuals eligible for educational support under the "G. I. Bill of Rights" will receive stipends to bring the total income from these two sources to the above rates.

Prospective candidates should apply at once, even though they are unable to undertake graduate study in the immediate future. Application blanks and further information can be obtained by writing to Secretary, Committee on Predoctoral Fellowships, National Research Council, 2101 Constitution Avenue, N. W., Washington 25, D. C.

Higher Education in the U. S. S. R.--In 1938 the number of colleges and universities jumped to 716, numbering 601,000 students. In 1943, the last date of available statistics, the number of colleges and universities approximated 750, including 619,000 students. That increase has occurred during this war. I might mention that in 1938 the number of graduate students alone was about 6,000....the total number of research institutions, that is, institutions devoted solely to research, in 1938, was 902, employing 29,000 fulltime research workers. So stated Samuel A. Corson of the Key Center of War Information, University of Minnesota.

NOTES AND PERSONALIA

(See also pp. 351, 387, 390, 429, 430, 440, 444, 455, 456, 458, 459, 460, and 462)

NOTES

International Council of Scientific Unions--A meeting of the Executive Committee of the International Council of Scientific Unions was held in London, England, December 4-5. The agenda included election of a President in succession to Professor Fabry who had resigned, and selection of members to fill vacancies on the Committee. Other matters related to finance; position of those adhering countries that were with the axis forces; report from the Secretary of the Committee on Science and Social Relations; the best course upon which to build existing organizations; more active participation by the Council in helping the various International Unions and in giving a lead to adhering countries; consideration of suggestions and criticisms received from National Committees and received in writing by the General Secretary; relations with proposed Educational and Cultural Organization of the United Nations; diplomatic convention; promotion of new International Unions and joint commissions or committees; changes of statutes; and place of meeting of the General Assembly. Among the Americans in attendance were J. A. Fleming, a member of the Executive Committee, and R. M. Field and W. D. Lambert as guests. A report on the proceedings of the meeting will be published in a subsequent issue of the Transactions.

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(See also pp. 338, 357, 366, 378, 392, 414, and 450)

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EXPLOSION-BRECCIA IN THE WRANGELL DISTRICT, SOUTHEASTERN ALASKA

H. R. Gault

Abstract

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United States Department of the Interior)

Unusual breccias were noted at several places in the vicinity of Groundhog and Glacier Basins, about 13 miles east of Wrangell on the mainland of southeastern Alaska, in 1942 and 1943. They are similar in some respects to the clastic dikes in Colorado described by BURBANK [see 1 of "References" at end of paper] and HAFF [2], and to some explosion breccias in the Samoan Islands described by STEARNS [3].

The breccias are in a band of schists and gneisses which are flanked on the east by the Coast Range batholith and on the west by a large sill-like mass of quartz diorite. The bedding and cleavage of the metamorphic rocks strike about north 25° west and dip 60° northeast. Many fractures and faults with small observed displacements and quartz-porphyry sills and dikes cut the metamorphic rocks and the quartz diorite. Most of the quartz porphyry lies in a zone 2,000 feet wide in the western half of the band of metamorphic rocks. In Groundhog Basin, two miles northwest of Glacier Basin, a granite sill in the metamorphic rocks terminates abruptly southward except for a few apophyses which continue as quartz-porphyry sills.

Quartz-fluorite veins containing a little topaz cut the metamorphic rocks and some of the quartz-porphyry bodies, and are most numerous where quartz porphyry is most abundant. Topaz and fluorite also occur in some of the quartz-porphyry sills.

Basic sills and dikes are distributed throughout the area but are fewer and smaller than the quartz-porphyry bodies. Their age with respect to the breccias is unknown.

The breccias were seen at four localities, the two largest bodies being on the north side of Glacier Basin. The more westerly of these two bodies is in a shallow, elliptical crater-like depression about 450 feet long by 250 feet wide with the long axis parallel to the bedding of the metamorphic rocks. The contact of the breccia is sharp and generally cuts across the bedding of the country-rock. Although this mass is 1,500 feet east of the nearest outcrop of quartz porphyry, porphyry blocks from six inches across to two feet by ten feet make up nearly ten per cent of the breccia. The other 90 per cent is made up of fragments of metamorphic rocks. The other large mass of breccia is a sill about 125 feet wide and several hundred feet long and shows similar relations.

Narrow sills and dikes of breccia, some of which are connected, are exposed on the high ridge between Glacier and Groundhog Basins about one-half mile northwest of the two larger masses. The dikes and sills are several hundred feet long and are two inches to 18 inches in width, though most of them are less than 12 inches in width. Locally the sills swell and pinch. These rocks are darker than the breccia of the two larger bodies and are made up of about 35 per cent of quartz porphyry and 65 per cent of metamorphic rocks. The larger fragments range from one inch to three inches across and constitute 65 to 75 per cent of the rock; some of them are sharply angular and others are well rounded.

Breccias similar to those north of Glacier Basin occur at two places on the northeast side of Groundhog Basin. One of the breccias forms a sill-like mass intruded into the metamorphic rocks and the other is a sheet in the granite sill near its termination.

The breccias contain no material other than broken and crushed rock. They are made up of altered fragments of metamorphic rock and quartz porphyry in a finer-grained matrix of similar materials which has been annealed into a competent rock. The fragments of metamorphic rock are similar to the metamorphic rocks in the vicinity of the breccia although they are somewhat altered. The larger fragments are less altered than the fine material and the degree of alteration of the breccia as a whole varies from place to place. The bedding of the country-rock is undisturbed and there is no shattering at or near the contact. Only near the large masses of breccia is the wall-rock altered and there the alteration is slight.

The principal constituent of the matrix is chlorite which was derived from biotite and hornblende in the metamorphic rocks; most of the remainder consists of quartz, sericitized feldspar, and small fragments of altered rock. Fluorite occurs in some fragments of quartz porphyry, and topaz and fluorite observed in the matrix of some specimens may be residual from quartz porphyry.

The cross-cutting relations and quartz-porphyry fragments show that the breccias are not beds in the metamorphic series. The tabular forms of some of the bodies and the elliptical outline of others, the sharp and irregular cross-cutting contacts, the absence of shattering of the country-rock, and the fragments of material unlike the adjacent wall-rock are features that cannot all be due to faulting. The breccias are believed to be most readily explained by injection.

The alteration and annealing of the fragments and matrix suggests hydrothermal action by hot tenuous fluids, possibly gases. The mixture of well-rounded and angular fragments indicates that some of the material was subjected to strong abrasive action which in turn suggests that injection was probably rapid and turbulent. The breccias, therefore, are believed to have been emplaced by injection of broken rock from below, through the explosive escape of hot gases or very tenuous fluids which had sufficient energy to carry the fragments upward and further comminute them.

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Washington 25, D. C.

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NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 429, 430, 440, 444, 455, 456, 458, 459, 460, and 462)

PERSONALIA

Gilbert T. Rude of the United States Coast and Geodetic Survey retired after 42 years of service. Since his graduation from Washington College he has served the Bureau in many capacities. In addition to various field assignments he has served as Chief of the Division of Tides and Currents and later as Chief of the Division of Coastal Surveys which position he held at the time of his retirment. During these years of service oustanding developments and improvements were made in tide gages, the use of echo sounding and radio acoustic ranging, the application of radar to surveying, and many other phases of survey work. His invention, the Rude Star Finder, is found on most naval vessels. Several of the ships of the Survey were constructed under his direction. He is a member of several engineering and scientific organizations. He served as Secretary of the Section of Oceanography of the American Geophysical Union (1923 to 1926) and Vice-Chairman of the same section (1926-1928). He has also been an active member of the International Hydrographic Bureau.

Walter L. Youngquist has again taken up active work in geology at the University of Iowa after duty with the United States Navy.

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PRELIMINARY CHEMICAL CORRELATION BETWEEN CHROMITES AND THE CONTAINING ROCKS

T. P. Thayer

Abstract

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It is proposed that chemical analyses of chromites be expressed in terms of normative chromite, $(Mg, Fe)Cr_2O_4$, spinel, $(Mg, Fe)Al_2O_4$, and magnetite, Fe_3O_4, with the ratio of MgO to total FeO, thus: $Cr_{60}Al_{35}Mt_5\ (Mg_{61}Fe_{39})$. Since the magnetite and FeO can be readily calculated by difference, the formula in most instances can be shortened to $Cr_{60}Al_{35}(Mg_{61})$. All spinel analyses must be reduced to this form for plotting on the triangular prism of composition described by STEVENS, and for ready comparison with the silicates associated with them.

Reaction between spinel-rich chromite and diopsidic gabbro to form feldspar and olivine is shown in some Cuban deposits where pegmatitic gabbro was injected into brecciated chromite. The absence of any chromium-rich silicate there is regarded as evidence that under certain conditions the spinel fraction of the chromite molecule may react with the silicate environment without loss of chromium. According to this hypothesis, chromite crystallizing from troctolite should be rich in spinel, but chromite impoverished in spinel and therefore enriched in normative chromite and magnetite might occur in troctolite as a result of reaction between gabbro and spinel-rich chromite under equilibrium conditions. In general, chromites occurring in troctolites appear to be relatively rich in normative spinel, and chromites associated with pyroxene are richer in normative chromite and magnetite. Chromites in dunite show a very wide range in composition.

A plot of 60 complete analyses made in the laboratory of the United States Geological Survey shows that the chromites of western North America and the Caribbean region fall in groups which overlap somewhat, but are nevertheless distinct. The chromites from Cuba, Guatemala, and Venezuela, which occur in dunite and troctolite, have the general formula $Cr_{25-80}Al_{15-75}Mt_{1-5}\ (Mg_{65-75})$ and average about $Cr_{50}Al_{47}(Mg_{70})$. The Stillwater chromites, which occur in harzburgite, fall in the range $Cr_{52-69}Al_{26-39}Mt_{5-10}(Mg_{45-61})$ and average about $Cr_{60}Al_{32}(Mg_{52})$. The chromites of the Pacific Coast occur in dunite and average about $Cr_{70}Al_{24}(Mg_{60})$, with the following range: $Cr_{60-77}Al_{16-35}Mt_{3-12}(Mg_{45-75})$.

[Note: The complete paper is to be published in a forthcoming issue of Economic Geology.]

United States Geological Survey,
Washington, D. C.

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ARTIFICIAL DRAINAGE OF LAND: STREAMLINE EXPERIMENTS

THE ARTESIAN BASIN - III

Don Kirkham

Abstract--Assuming DARCY'S law, mathematical relations are developed which describe the flow of surface-water and ground-water into drainage tubes, buried in waterlogged homogeneous soil overlying artesian gravel. LAPLACE'S equation is fundamental and is solved subject to these boundary conditions: the drain tubes are long, are equally spaced and are circular in cross section; the drain tubes, the upper soil surface and the lower soil surface (in contact with the artesian gravel) are all in horizontal planes; the pressure at the drains is atmospheric; the pressure at the upper surface is that of the atmosphere plus that due to the layer of surface-water; the pressure at the lower surface is that of the artesian water and is measured by the height to which water rises in a standpipe penetrating into the artesian gravel. Using infinite systems of images, two pairs of conjugate potentials are derived and from these potentials the drain-flux, the flow-distribution at the soil-surface, and the time for the surface-water to fall a given distance are derived. Either pair of conjugate potentials is strictly accurate for any values of the parameters, drain-depth, drain-spacing, drain-radius, thickness of soil overlying the artesian gravel, depth of surface-water, and height of standpipe-water, provided only (which is true in practice) that the radius of the drains is small compared to the distance to adjacent drains and to the boundaries of the soil. The conjugate potentials are expressed in infinite series. One pair is convenient for numerical calculations when the drain spacing is small, the other when the drain spacing is large. For intermediate spacings either expression may be used without undue labor. For practical purposes not more than two terms in an infinite series are required, regardless of the values of the parameters, when the proper potential form is chosen. Theoretically computed streamlines are compared with streamlines in a sand-tank model.

Introduction

In Parts I and II of this series (see [1] and [2] of "References" at end of paper) the flow of water from an artesian basin into horizontal equally spaced drains was considered. These papers were concerned with an experimental demonstration and a theoretical analysis of the case of flow, into horizontal equally spaced drains, of water originating solely from an artesian aquifer below the drains. The case then considered assumed there was no surface-water, such as might be present during or after a rainfall. In this paper it is the purpose to present the theory for the case when there is both artesian water and surface-water flowing into the drains. Reference will be made to the experimental work in sand-tank models by HARDING and WOOD [3], which strikingly illustrates the streamline flow of these cases.

In this paper, as in the analysis given in Part II, the velocity-potential, stream-potential, and drain-flux for the general case will be obtained, and also the theoretical streamlines will be compared with the specific experimental flow-patterns. In fact, the whole analysis will be similar to that of Part II, except for the significant difference that now conformal transformations will be used. In this method a complex potential-function is first derived, and this function yields immediately both the velocity-potential and stream-potential simultaneously. The velocity-potential is the real part of the complex potential, and the stream-potential is the imaginary part. Thus for every complex potential-function, the stream-functions may be obtained about as easily and as accurately as the velocity-potentials. This was not the case in Part II. There the velocity-potential could be obtained with great accuracy for a wide range of values of the ratio (drain-separation)/(artesian overburden); but the streamlines could be determined accurately--and then only with considerable effort--if this ratio was not greater than about one.

In this paper, as in Part II, it will be seen that the solutions are infinite series. In order to obtain rapidly convergent series, two sets of solutions will be obtained; then, regardless of whether the drain spacing is large or small, 3-figure accuracy of results can be obtained with use of not more than one or two terms in the infinite summations when the proper solution is used. The two sets of

solutions are further useful in that they serve as checks, one on the other, in numerical calculations.

The solutions to be given here are accurate only when the soil is waterlogged to the surface or when the water-table may be considered horizontal, and are therefore limited in that they do not consider the curvature of the water-table which results when surface-water is no longer supplied. Solutions for the problem which takes into account curvature of the water-table do not appear to be at hand. When solutions of the curvature problem are obtained, the present analysis should furnish a check on their validity, since the theory of the curvature problem should yield the same solution for zero curvature of the water-table as does the present problem.

While awaiting a complete theory which includes not only curvature but also the effect of planar boundaries such as the artesian basin in this problem (Figure 1), electrolytic model work, as has been shown by CHILDS [4], may be used to determine the drain-flux and the flow-patterns. The recognized difficulty with model work, however, is that for each geometrical configuration, for each different drain-depth or spacing, etc., a different model must be used. A complete theory, on the other hand, should give the equations for drain-flux, velocity-potential, and other quantities of interest for any parameters which may occur in the problem. The present solution does this for all geometries in which the water-table is flat.

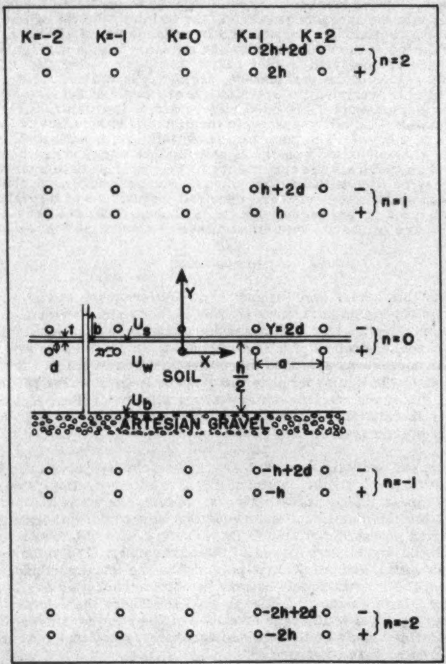

Fig. 1--Vertical section of field showing actual and image drains

The results and methods used in the present analysis may be used in the solution of other drainage problems, for example, those discussed in Parts I and II, and in another paper by the author where results, but not theoretical details, were given [5]. They may also be used in analogous problems in electrostatics, heat-flow, etc.

In the analysis which follows parenthetical notations such as (P:615), (P:666), etc., refer to formulas in PEIRCE'S Tables [6].

Analysis

Figure 1 shows a section of soil made by a plane perpendicular to the drains. Axes of x and y are chosen as indicated, and z is the complex variable $x + iy$. The radius of the drains is r, the spacing between them, a, and their depth, d. An artesian aquifer is at a depth $h/2$ and water-pressure in the aquifer is indicated by the height b above the soil-surface to which water stands in a stand pipe penetrating into the aquifer. The soil is homogeneous, is saturated to the surface, and there is surface-water of thickness t. The method of images is used. For the purpose of establishing appropriate image-systems, soil is imagined to extend to $+\infty$ above the actual upper soil-surface and to $-\infty$ below the lower soil-surface, the effect of a constant upward flow from the artesian gravel being taken into account after the image-system is established. The drains, actual or image, are taken positive or negative according as flux flows into the drains or out of them. With this convention the actual drains are positive. The image system is chosen to make the potential, due to the drains alone, equal to zero at the upper soil-surface. The lower surface could equally well be made a surface of zero potential by proper choice of images.

The actual drains are located at $y = 0$ and $x = -ka, \ldots -2a, -a, 0, a, 2a \ldots ka$, where k goes from $-\infty$ to $+\infty$. The images, in the soil-surface, of the actual drains are at $y = 2d$ and the same values of x. The images at $y = 2d$ are negative. The drains at $y = 0$ and $y = 2d$ may be considered a "doublet"-row. This doublet-row is indicated in the Figure by the bracket $n = 0$. The image, in the lower soil-boundary, of the doublet-row $n = 0$ is the doublet-row $n = -1$. The image in upper soil-surface of $n = -1$ is $n = 1$. The image in the lower soil-boundary of $n = 1$ is $n = -2$, etc., where n goes from $-\infty$ to $+\infty$. The y coordinates $y = 2d$, $y = h$, $y = h + 2d$, etc., for the image-drains are shown in the Figure.

When the image-system just described is established, it is observed that the system may be considered both as a series of horizontal rows at $y = 0$, $y = 2d$, $y = h$, etc., and also as a series of columns located at $x = -ka, \ldots -2a, -a, 0, a, 2a \ldots ka$. The potential at any point P, when considered as arising from the effect of the drains taken in columns, must be the same as the potential at the same point P arising from the drains taken in rows. It is this observation that leads to the alternate solutions.

Derivation of potentials by rows--The complex potential at the point P, considering the system of drains as comprised of horizontal rows, is first derived. This is done by summing at the point P the effect of the drains in a row and then summing the effect of the rows. The fundamental complex potential form w_1 is $w_1 = 2q \log z$, as may be seen by writing z in the polar form $Re^{i\theta}$, which yields $w_1 = u_1 + iv_1 = 2q \log Re^{i\theta} = 2q \log R + 2qi\theta$, the real part being $u_1 = 2q \log R$, a familiar form, the imaginary part being $v_1 = 2q\theta$. The equipotentials are circles obtained by giving u_1 constant values and the streamlines are radial lines obtained by assigning constant values to v_1. The coefficient 2 is used in the solution in order to obtain the drain-flux in a conventional form $4\pi q$. In the corresponding electrostatic problem q is the charge per unit length on the filament, and the total lines of force emanating from unit length of filament is $4\pi q$.

The complex potential $w_1 = 2q \log z$ is the value at the point P arising from the drain at (0,0). The potential at P due to the drain at (0,a) is $2q \log (z-a)$ and at (0,-a) it is $2q \log (z+a)$. The complex potential w_2 due to all the drains in the row $y = 0$ is

$$\begin{aligned} w_2 &= 2q[\log z + \log (z-a) + \log (z+a) + \log (z-2a) + \log (z+2a) + \ldots] \\ &= 2q \log z[z^2 - a^2][z^2 - (2a)^2] \\ &= 2q \left\{\log(\pi z/a)[1-(z/a)^2][1-(z/2a)^2] \ldots + \log(a/\pi)(-1)^k \prod_{k=1}^{\infty}(ka)^2\right\} \end{aligned}$$

that is,

$$w_3 = 2q \log \sin \pi z/a \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where the infinite constant has been dropped and use has been made of the infinite product form of the sine-function (P:816).

In order that the complex potential yield a real part of simple form, the quantity $q \log 2^{(1/2)}$ is added to w_3 giving

$$\begin{aligned} w_4 &= 2q \log \sin \pi z/a + q \log 2^{(1/2)} \\ &= q \log 2 \sin^2 \pi z/a = q \log (1 - \cos 2\pi z/a) \end{aligned}$$

or since

$$\text{vers } A = 1 - \cos A$$

the expression w_4, for conciseness of notation, may be written

$$w_4 = q \log \text{vers } 2\pi z/a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$= q \log \text{vers } (2\pi x/a + i2\pi y/a)$$

a fundamental form, the real part u_4 and the imaginary part v_4 of which, as is seen in Appendix I, are respectively

$$u_4 = q \log (\cosh 2\pi y/a - \cos 2\pi x/a) \ldots\ldots\ldots\ldots\ldots (3)$$

and

$$v_4 = 2q \tan^{-1} (\tanh \pi y/a \cot \pi x/a) \ldots\ldots\ldots\ldots\ldots (4)$$

Equation (3) may be derived independently of the theory of complex potentials (see for example [7, p. 525]).

If the form $2q \log \sin \pi z/a$ had been used as basic, equation (3) would be $u = q \log[(1/2)(\cosh 2\pi y/a - \cos 2\pi x/a)]$. Use of the versine form eliminates the coefficient (1/2). MAXWELL derived expressions of the form of equations (3) and (4) in the solution of the problem of flow of electricity in a slotted plate [8, p. 298]. He apparently overlooked the application of the forms to the infinite grating problem, for which, using other forms, he gives an approximate solution applicable for closely spaced drains [8, p. 310]. Equations (3) and (4) yield the solutions to the slotted plate problem and its hydrodynamic analogue if $2\pi x/a$ and $2\pi y/a$ are taken as potentials and u_4 and v_4 as coordinates.

The potential due to all the rows can now be evaluated. At the row $y = 2d$ it is

$$-q \log \text{vers } 2\pi(z - 2di)/a$$

Combining this with equation (3), the value for the row $y = 0$, we obtain

$$q \log (\text{vers } 2\pi z/a)/[\text{vers } 2\pi(z - 2di)/a]$$

as the potential due to the doublet-row $n = 0$ in Figure 2.

Similarly the complex potential for $n = 1$ is

$$q \log [\text{vers } 2\pi(z - hi)/a]/[\text{vers } 2\pi(z - 2di - hi)/a] \ldots\ldots\ldots\ldots\ldots (5)$$

and for $n = -1$ is

$$q \log [\text{vers } 2\pi(z + hi)/a]/[\text{vers } 2\pi(z - 2di + hi)/a]$$

etc. Summing the effect of the doublet-rows we obtain the complex potential w_n arising from all the rows. It is

$$w_n = u_n + iv_n = q \sum_{n=-\infty}^{\infty} \log[\text{vers } 2\pi(z - nhi)/a]/[\text{vers } 2\pi(z - 2di - nhi)/a] \ldots\ldots (6)$$

or substituting $z = x + iy$

$$w_n = q \sum_{n=-\infty}^{\infty} \log[\text{vers } 2\pi(x + iy - nhi)/a]/[\text{vers } 2\pi(x + iy - 2di - nhi)/a] \ldots\ldots\ldots\ldots (6a)$$

which yields with the aid of Appendix I

$$u_n = q \sum_{n=-\infty}^{\infty} \log [\cosh 2\pi(y - nh)/a - \cos 2\pi x/a]/[\cosh 2\pi(y - 2d - nh)/a - \cos 2\pi x/a] \ldots\ldots (7)$$

and

$$v_n = 2q \sum_{n=-\infty}^{\infty} \tan^{-1}[\cot \pi x/a \tanh \pi(y - nh)/a] - \tan^{-1}[\cot \pi x/a \tanh \pi(y - 2d - nh)/a] \ldots\ldots (8)$$

The inverse tangent terms in equation (8) may be combined. It is found with the temporary aid of the substitutions $y - nh = y' + d$, $y - 2d - nh = y' - d$ that

$$v_n = 2q \sum_{n=-\infty}^{\infty} \tan^{-1}[\sinh 2\pi d/a \sin 2\pi x/a]/[\cosh 2\pi(y - d - nh)/a - \cosh 2\pi d/a \cos 2\pi x/a] \quad (8a)$$

Equations (7), (8), and (8a) are the desired results. In these equations all terms in the summations, except the term for which $n=0$, are generally quite negligible if h is greater than a.

Derivation of potentials by columns--Equations (6), (7), and (8) give potential expressions due to the drains and image-system considered in rows. The alternate expression for the complex potential at the point P is now derived by considering the drains in columns.

Proceeding in the manner used in obtaining equation (1), it is found that the complex potential at the point P, due to all the positive drains in the column $k=0$, is

$$2q[\log z+\log(z-hi)+\log(z+hi)+\log(z-2hi)+\log(z+2hi)+\ldots]=2q\log z[z^2-(hi)^2][z^2-(2hi)^2][z^2-(3hi)^2]$$
$$=2q\left\{\log(\pi iz/h)[1-(iz/h)^2][1-(iz/2h)^2][1-(iz/3h)^2]\ldots+\log(h/\pi i)\prod_{1}^{\infty}(nh)^2\right\}=q\log\operatorname{vers}2\pi iz/h$$

where as before we have dropped an infinite constant.

Similarly, due to all the negative drains in the column $k=0$, the complex potential at P is

$$-q\log\operatorname{vers}2\pi i(z-2di)/h$$

so that the complex potential due to all the drains, positive and negative, in the row $k=0$ is

$$q\log[\operatorname{vers}2\pi iz/h.]/[\operatorname{vers}2\pi i(z-2di)/h]$$

Likewise the complex potential due to all the drains in the column $k=1$ is

$$q\log[\operatorname{vers}2\pi i(z-a)/h]/[\operatorname{vers}2\pi i(z-2di-a)/h]$$

and in the column $k=-1$ is

$$q\log[\operatorname{vers}2\pi i(z+a)/h]/[\operatorname{vers}2\pi i(z-2di+a)/h]$$

etc. Summing the effect of all the columns the total complex potential w_k at P can now be written down. It is

$$w_k=u_k+iv_k=q\sum_{k=-\infty}^{\infty}\log[\operatorname{vers}2\pi i(z-ka)/h]/[\operatorname{vers}2\pi i(z-2di-ka)/h]\ \ldots\ldots\ldots\ldots\ (9)$$

or putting $z=x+iy$

$$w_k=q\sum_{k=-\infty}^{\infty}\log[\operatorname{vers}2\pi(-y+ix-ika)/h]/[\operatorname{vers}2\pi(-y+2d+ix-ika)/h]$$

or

$$w_k=q\sum_{k=-\infty}^{\infty}\log[\operatorname{vers}2\pi(y-ix+ika)/h]/[\operatorname{vers}2\pi(y-2d-ix+ika)/h]\ \ldots\ldots\ldots\ldots\ (9a)$$

since the versine is an even function.

It is now found with the aid of Appendix I that the forms alternate to those of equations (7), (8), and (8a) are

$$u_k=q\sum_{k=-\infty}^{\infty}\log[\cosh 2\pi(x-ka)/h-\cos 2\pi y/h]/[\cosh 2\pi(x-ka)/h-\cos 2\pi(y-2d)/h]\ \ldots\ (10)$$

$$v_k=-2q\sum_{k=-\infty}^{\infty}\{\tan^{-1}[\cot\pi y/h\ \tanh\pi(x-ka)/h]-\tan^{-1}[\cot\pi(y-2d)/h\ \tanh\pi(x-ka)/h]\}\ \ldots\ (11)$$

$$v_k=-2q\sum_{k=-\infty}^{\infty}\{\tan^{-1}[\sin 2\pi d/h\ \sinh 2\pi(x-ka)/h]/[\cos 2\pi(y-2d)/h-\cos 2\pi d/h\ \cosh 2\pi(x-ka)]/h\}\quad (11a)$$

Equations (9), (10) and (11) are the desired results. Equations (10) and (11) are not only suitable for the present problem of an infinite number of equally spaced drains but are also suitable for the problem of a finite number of drains. For a single drain the potentials u_k and v_k are obtained by using only the $k=0$ terms. For two drains the terms $k=0$ and $k=1$ or $(k=-1)$ are used, etc. The $k=0$ case may be compared with expressions for the electrostatic problem--a single filament between infinite planar electrodes--as given for example by SMYTHE [9]. For any finite number of drains the complex potential, equation (9) may be compared with a result given by BARKAS [10], who has obtained an unusual solution in gamma functions for the electrostatic problem corresponding to a finite number of drains with the lower boundary (artesian gravel) at a great depth. In most problems involving equations (10) and (11) the $k=0$ terms suffice even if there are an infinite number of drains, provided a is greater than h.

General solution of problem--The general solution of the problem can now be given. It is, using equations (6), (7), (8), (9), (10), and (11),

$$W_n = U_n + iV_n = A_1 + B_1 iz + q \sum_{n=-\infty}^{\infty} \log[\text{vers } 2\pi(z-nhi)/a]/[\text{vers } 2\pi(z-2di-nhi)/a] \ldots\ldots (12)$$

$$U_n = A_1 - B_1 y + u_n \ldots\ldots (13)$$

$$V_n = B_1 x + v_n \ldots\ldots (14)$$

or alternately it is

$$W_k = U_k + iV_k = A_2 + B_2 iz + q \sum_{k=-\infty}^{\infty} \log[\text{vers } 2\pi i(z-ka)/h]/[\text{vers } 2\pi i(z-2di-ka)/h] \ldots\ldots (15)$$

$$U_k = A_2 - B_2 y + u_k \ldots\ldots (16)$$

$$V_k = B_2 x + v_k \ldots\ldots (17)$$

In the above the A's and B's are (real) constants to be determined by the boundary conditions. The term iBz provides for a constant vertical flow in the system, whereas the term A provides for a superposed constant potential. The term iBz is necessary because the solution given here, being general, must include the case of strictly vertical flow which would result if the drains were infinitesimally small. If the drains are infinitesimally small, the third term in equation (12) will vanish since q, the drain-flux coefficient, will be zero, and the flow will accordingly be vertical and uniform everywhere in the medium, a condition described by the first two terms alone.

The methods used in evaluating A_2 and B_2 are the same as those used in evaluating A_1 and B_1. The latter pair of constants will be evaluated; the former pair will be given without details of computation.

The boundary conditions are as follows:

(a) At the surface of the soil the pressure is that due to the atmosphere plus that due to the layer of water of thickness t (see Fig. 1).

(b) The pressure at the drains is atmospheric. (Here it is assumed that hydrostatic and hydrodynamic effects inside the drain may be neglected.)

(c) The pressure at the soil-gravel interface is constant, and is equal to the pressure of the atmosphere plus the pressure due to a column of water of height (h/2 + b).

The boundary potentials corresponding to these conditions may be obtained from the relation [7, p. 287 and p. 129]

$$U = K(p + \gamma g y) \ldots\ldots (18)$$

where U is given by equations (13) and (16), K is the ratio of the permeability of the soil as defined by MUSKAT [7, Chapter II] to the viscosity of the water, p is the pressure at a point in the medium, an unknown which may be found when V is established, γ is the density of water in cgs units, and g is the acceleration due to gravity in cgs units.

Defining now U_s, U_w, and U_a as the potential respectively at the upper soil-surface, at the drain and at the lower soil-surface, it is found from equation (18) and the boundary conditions that

$$\left.\begin{array}{l} U_s = K[p_o + \gamma g(t + d)] \\ U_w = K p_o \\ U_a = K[p_o + \gamma g(b + d)] \end{array}\right\} \ldots\ldots (19)$$

From these expressions there can also be written down for later reference

$$U_a - U_s = K[\gamma g(b - t)] \ldots\ldots (20)$$

$$U_s - U_w = K\gamma g(t + d) \ldots\ldots (21)$$

expressions which give respectively the difference in potential between the lower boundary and upper boundary, and between the lower boundary and the drain. These values correspond to voltage differences in the electrostatic problem.

Let u_s, u_w, and u_a be the values of u respectively at the surface of the soil (y=d), at the drains (y=r, x=0, say) and at the lower surface (Y=-h/2+d), and let U_s, U_w, and U_a be the corresponding values of U_n; then from equation (13)

$$\left.\begin{aligned} U_s &= A_1 - B_1 d + u_s \\ U_w &= A_1 + u_w \\ U_a &= A_1 + B_1(h/2-d) + u_a \end{aligned}\right\} \quad (22)$$

where a term $(-B_1 r)$ in the second equation has been dropped since it will be small.

The values u_s, u_w, and u_a are now obtained. Putting y=d in equation (7), or by direct inspection of the image system of Figure 1, it is seen immediately that $u_s=0$. Putting y=-h/2+d in equation (7), it can be verified that $u_a=-4\pi qd/a$. It is easier, however, to get this result by observing in Figure 1 that, at the lower surface, the doublet-row n=0 cancels n=-1, n=1 cancels n=-2, etc., leaving always an uncancelled term of the form

$$q \log [\mathrm{vers}\ 2\pi(z-nhi)]/[\mathrm{vers}\ 2\pi(z-2di-nhi)]$$

of which the real part

$$q \log [\cosh 2\pi(y-nh)/a - \cos 2\pi x/a]/[\cosh 2\pi(y-2d-nh)/a - \cos 2\pi x/a]$$

when $n \to \infty$ must yield the value u_a. The quantity u_a is then seen to be $-4\pi qd/a$, since when n is large, $\cos 2\pi x/a$ is negligible and $\cosh nA = e^{nA}/2$, A being any real number.

To evaluate u_w, y in equation (8) is put equal to r, x is put equal to 0, and r is neglected compared to h, d, etc. It is found, then, (P:666, 657) that

$$u_w = q \log (\cosh 2\pi r/a-1)/(\cosh 4\pi d/a-1) + \sum_{n=1}^{\infty}(\cosh 2\pi nh/a-1)/(\cosh 2\pi nh/a - \cosh 4\pi d/a)^2$$

$$= q \log (2 \sinh^2 \pi r/a)/(2 \cosh^2 2\pi d/a) + \sum_{n=1}^{\infty}(2 \sinh^2 \pi nh/a)^2/[(\cosh 2\pi nh/a-1)-(\cosh 4\pi d/a-1)]^2$$

$$= 2qe_n \quad (23)$$

where

$$e_n = \log (\sinh \pi r/a)/(\sinh 2\pi d/a) + \sum_{n=1}^{\infty} \log (\sinh^2 \pi nh/a)/(\sinh^2 \pi nh/a - \sinh^2 2\pi d/a) \quad (24)$$

Putting the values for u_s, u_w, and u_a in equations (22) and solving, it is found that

$$A_1 = U_s + (2d/h)(U_a - U_s + 4\pi qd/a) \quad (25)$$

$$B_1 = (2/h)(U_a - U_s + 4\pi qd/a) \quad (26)$$

$$q_n = -[(U_s - U_w) + 2d(U_a - U_s)/h]/[2(e_n + 4\pi d^2/ah)] \quad (27)$$

where the subscript n is used with q to distinguish it from the alternate form q to follow.

Likewise, it is found that

$$A_2 = U_s + (2d/h)(U_a - U_s) \quad (28)$$

$$B_2 = (2/h)(U_a - U_s) \quad (29)$$

$$q_k = -[(U_s - U_w) + 2d(U_a - U_s)/h]/2e_k \quad (30)$$

where

$$e_k = \log (\sin \pi r/h)/(\sin 2\pi d/h) + \sum_{k=1}^{\infty} \log (\sinh^2 \pi ka/h)/(\sinh^2 \pi ka/h + \sin^2 2\pi d/h) \quad (31)$$

and $2e_k$ is the value of u_k/q_k at the drain.

In equations (27) and (30), above, the numerators are equal; accordingly, since $q_k = q_n$, the denominators are also equal, and when equated they offer an interesting result. The numerators of both equation (27) and (30) are negative, making q_k and q_n positive. In equations (25), (26), (27), and (28), (29), and (30) the constants A_2, B_2, and q_k are simpler than A_1, B_1, and q_n by virtue of the vanishing value of u_k, both at the upper and lower soil surface.

With the aid of equations (19), (20), and (21) the constants A_1, B_1, q_n, A_2, B_2, and q_k as given by equations (25) to (30) can be obtained in terms of the original data K, γ, t, b, these new values giving, when substituted in equations (13), (14), (16), and (17), the alternate solutions for the velocity potentials U_n and U_k and the stream-potentials V_n and V_k. Thus it is found that

$$U_n = Kp_o + K\gamma g(t+d) + 2(d-y)[K\gamma g(b-t) + 4\pi q_n d/a]/h$$

$$+ q_n \sum_{n=-\infty}^{\infty} \log[\cosh 2\pi(y-nh)/a - \cos 2\pi x/a]/[\cosh 2\pi(y-2d-nh)/a - \cos 2\pi x/a] \;.\;.\;.\;.\;(32)$$

$$U_k = Kp_o + K\gamma g(t+d) + 2K\gamma g(b-t)(d-y)/h$$

$$+ q_k \sum_{k=-\infty}^{\infty} \log[\cosh 2\pi(x-ka)/h - \cos 2\pi y/h]/[\cosh 2\pi(x-ka)/h - \cos 2\pi(y-2d)/h] \;.\;.\;.\;.\;(33)$$

$$V_n = (2/h)[K\gamma g(b-t) + 4\pi q_n d/a]/x + 2q_n \left\{\tan^{-1}[\tanh \pi(y-nh)/a \cot \pi x/a] - \tan^{-1}[\tanh \pi(y-2d-nh)/a \cot \pi x/a]\right\} \;.\;.\;.\;(34)$$

$$V_k = 2K\gamma g(b-t)x/h - 2q_k \left\{\tan^{-1}[\tanh \pi(x-ka)/h \cot \pi y/h] - \tan^{-1}[\tanh \pi(x-ka)/h \cot \pi(y-2d)/h]\right\} \quad (35)$$

where

$$q_n = -K\gamma gd[1+t/d+2(b-t)/h]/2(e_n + 4\pi d^2/ah) \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;(36)$$

$$q_k = -K\gamma gd[1+t/d+2(b-t)/h]2e_k \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;(37)$$

and e_n and e_k are given by equations (24) and (31), respectively.

Equations (32) to (37) inclusive constitute the complete solution of the problem. Each solution is accurate for all values of x and y in the soil. Equations (32), (34), and (36) should in general be used when h is larger than a and equations (33), (35), and (37) when a is larger than h. The suitable solution having been chosen, various quantities of interest may be obtained. Equipotential lines may be plotted by drawing lines through sets of constant values of U and streamlines by drawing lines through sets of constant values of V. The y-component of flow (cm^3 per cm^2 per second) at any point in the soil is given by $-\partial U/\partial y$ and the x-component by $-\partial U/\partial x$. The total drain-flux in cm^3 per cm length of drain may be obtained by integrating $-\partial U/\partial y$ with respect to x over a strip 1 cm wide and 1 cm long perpendicular to the drains at the upper and the lower surfaces of the soil; or it may be more simply obtained by evaluating the normal derivative $\partial U/\partial n$ over the surface of a drain. If this is done, it is noted in equation (32) that all quantities when considered over the small region of a drain are essentially constant, except the quantity $q_n \log(\cosh 2\pi y/a - \cos 2\pi x/a$. This term, since $2\pi y/a$ and $2\pi x/a$ are small, may be written (P:791, 773) as $q_n \log[(2\pi/a)^2(y^2+x^2)] = q_n \log(2\pi/a)^2 r^2 = 2q_n \log 2\pi r/a$, where r is the distance from the center of the drain to a point in the soil near the drain. The normal derivative of this expression is then simply its derivative with respect to r, that is, $\partial U/\partial n = \partial U/\partial r = 2q_n/r$ is the quantity of water flowing radially across a square centimeter of area near the drain. Taking r as the radius of the drain and integrating over the surface of 1 cm length of drain, the drain flux Q'_n per centimeter length of drain is seen to be

$$Q'_n = 2\pi r \cdot 2q_n/r = 4\pi q_n = 4\pi q_k$$

Numerical calculations

Comparison of experimental and theoretical streamlines--Some numerical calculations which illustrate the theory will now be given. Figure 2 (a), (b), and (c) shows streamlines obtained by HARDING and WOOD [3] in a sand-tank model for cases corresponding to the present problem. In each of the figures the streamlines correspond to field conditions in which the artesian overburden h/2 (Figure 1) is 50 ft, the drain depth d is nine feet, and the artesian pressure b is three feet. In Figure 2 (a) the drain spacing a is 40 ft, in (b) it is 80 ft, and in (c) it is 160 ft. Theoretical streamlines (circles) are plotted on the experimental streamlines. In Figure 2, (a) and (b), equation (34) is used for the theoretical calculations and in Figure 2 (c) equation (35) is used. Actually, for the calculations, equations (34) and (35) were put in the following form, using equations (36) and (37).

$$V_n/K\gamma g = \left\{-d[1+t/d+2(b-t)/h]/(e_n+4\pi d^2/ah)\right\}P_n + \left\{-4\pi d^2[1+t/d+2(b-t)/h \;/[(e_n+4\pi d^2/ah)ah] + 2(b-t)/h\right\}x \;.\;.\;.\;(38)$$

where

$$P_n = \sum_{-\infty}^{\infty} \tan^{-1}[\cot \pi x/a \cdot \tanh \pi(y-nh)/a] - \tan^{-1}[\cot \pi x/a \cdot \tanh \pi(y-2d-nh)/a] \;.\;.\;.\;.\;.\;(38a)$$

and

$$V_k/K\gamma g = \left\{d[1+t/d+2(b-t)/h]/e_k\right\}P_k+[2(b-t)/h]x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

where

$$P_k = \sum_{k=-\infty}^{\infty}\left\{\tan^{-1}[\tanh \pi(x-ka)/h \cdot \cot \pi y/h]+\tan^{-1}[\tanh \pi(x-ka)/h \cdot \cot \pi(2d-y)/h]\right\} \quad \ldots \quad (39a)$$

where in equation (38a) only the n=0 term is required for Figure 2 (a) and (b), and in equation (39a) only the k=0 term is required, except for lines 3.42 and 2.98 of Figure 2 (c).

HARDING and WOOD [3] do not specify the drain-radius r or the thickness t of the layer of water maintained at the surface of the soil. The radius r in each case is probably 1/2 ft, a value used in [5]. The thickness t of the surface-water is calculated from the experimental data with the aid of the theory. This is done by substituting the values of x and y for two points on a streamline into the equation, eliminating $V_n/K\gamma g$ (or $V_k/K\gamma g$), and solving for t. It is found that t for Figure 2 (a) is 1.345 ft; for Figure 2 (b), 1.83 ft; and for Figure 2 (c), 1.70 ft.

Having now the values a, d, h/2, r, t, and b for each figure, the coefficients of P and x in equations (38) and (39) can be computed. When this is done the streamline equations become:

Figure 2 (a) $V_n/K\gamma g = 2.92\ P_n + 0.1157x$

Figure 2 (b) $V_n/K\gamma g = 3.09\ P_n + 0.0698x$

Figure 2 (c) $V_k/K\gamma g = -3.13\ P_k + 0.0234x$

where P_k is negative.

Substitution of values of x and y for points on any particular streamline in one of the above equations should yield a constant value for the right hand side of the equation. Actually the calculations show that the points in the figures correspond to values of $V_k/K\gamma g$ accurate to within 1.5 per cent of the mean value. This is illustrated for streamline 2.98 of Figure 2 (c) in Table 1, which also gives the value of P_k corresponding to each point. In the last four values of P_k the value π has been used to indicate that the terms in P_k are not evaluated in the first quadrant.

Table 1--Table of values for theoretical stream function ($V_k/K\gamma g$) for points on the streamline 2.98 of Figure 2 (c). In this figure a = 40 ft, h/2 = 50 ft, d = 9 ft, r = 1/2 ft, b = 3 ft, t = 1.83 ft. See Figure 1 for meaning of symbols.

Point				Point			
x	y	P_k	$V_k/K\gamma g$	x	y	P_k	$V_k/K\gamma g$
feet	feet			feet	feet		
55.3	-36.4	-.536	2.97	40.2	4.5	$2.489-\pi$	2.99
54.2	-26.5	-.533	2.94	35.8	6.5	$2.455-\pi$	3.00
51.7	-16.6	-.561	2.95	32.7	4.67	$2.432-\pi$	2.99
47.9	- 7.3	-.591	2.97	24.4	0	$2.364-\pi$	3.01
43.5	0	-.626	2.98				2.98 av.

The values of $V/K\gamma g$ for the several streamlines for which theoretical computations were made are shown in Figure 2 on the streamlines. The significance of these values is that when the difference is taken between any two of them and multiplied by $K\gamma g$, the result gives the quantity of water per unit time per unit length of drain which flows between those two lines. As a particular case, the drain-flux may be obtained by taking the difference between the value for the line at x=0, which flows vertically downward into the drain, and the value of the line at x=0, which flows vertically upward into the drain, and multiplying this difference by $2K\gamma g$. Thus for Figure 2 (c) the drain-flux is $2K\gamma g(9.84-0)$ per unit length of drain. The factor 2 is used so that the water flowing into each half of the drain will be included.

Spacing of drains--GARDNER and his associates have pointed out [11] that the use of tile drains in land overlying artesian gravel will not be economic because of the close spacing required. The present theory shows that with surface-water as well as artesian water, the drain-spacing must be even closer than that required for the case of artesian water alone, if the space midway between drains at the surface of the soil is to be drained, that is, if the water midway between the drains at the surface of the soil is to flow toward the drains rather than toward the space above the surface of the soil. A calculation making use of the present theory (see next section) and that developed previously [2] shows that with drains at 9 ft, artesian gravel at 50 ft, a drain radius 1/2 ft, and an

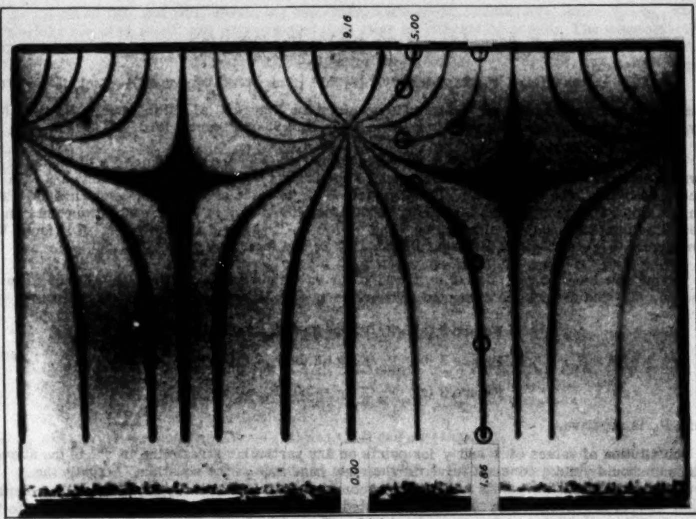
9.16
5.00
0.00
1.86

Fig. 2(a)

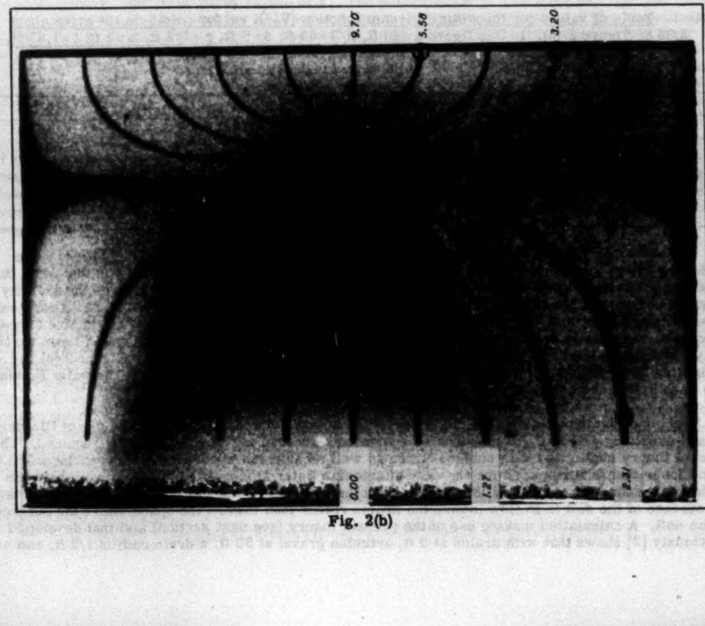
9.70
5.58
3.20
0.00
1.27
2.31

Fig. 2(b)

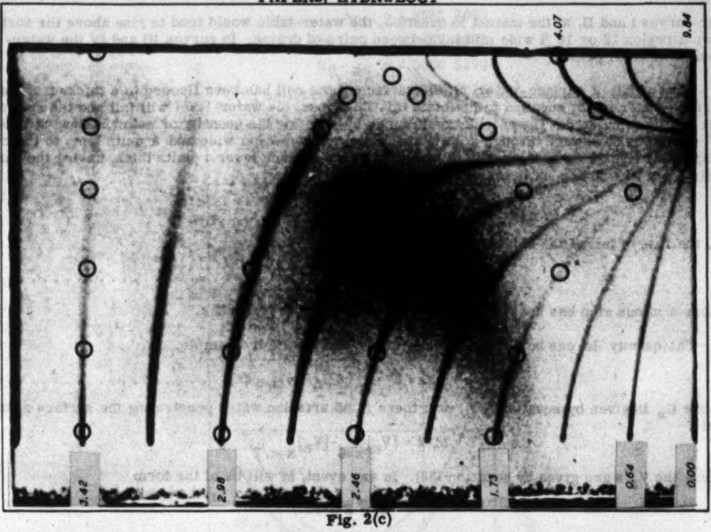

Fig. 2(c)

Fig.2--Streamlines obtained experimentally by HARDING and WOOD in a sand-tank model. Depth of drain, 9 feet; thickness of soil overlying artesian gravel, 50 feet; radius of drain 1/4 foot. The theoretical streamlines are indicated by circles. (a) 40-foot separation drains; (b) 80-foot separation; (c) 160-foot separation

artesian head 4-1/2 ft, the space at the surface of the soil midway between the drains will be drained for artesian water alone, if the drains are spaced closer than 88 ft; but if there is both surface- and artesian-water, the drains must be spaced closer than 40 ft.

Flow at the upper soil surface--At the surface of the soil, the volume of water $\partial U/\partial y$ flowing vertically through unit area of soil-surface per unit time is obtained by differentiating equation (32) or (33) with respect to y and setting y in the result so obtained equal to d. The result, using equation (32) and taking t=0 is

$$(\partial U_n/\partial y)/K\gamma g_{\,y=d} = 2b/h - [2\pi d(1+2b)/h)/a(e_n+4\pi d^2/ah)][2d/h-(\sinh 2\pi d/a)/(\cosh 2\pi d/a-\cos 2\pi x/a)] \quad ..(40)$$

where only the n=0 term in equation (32) has been used, since the other terms for the applications to be discussed below contribute negligible effect.

Figure 3 shows a plot of the left-hand side of this equation versus x. The ordinates must be multiplied by 1.89×10^{-6} to obtain the flow in cubic feet per square foot per minute per millidarcy [7]. Positive values of the ordinates indicate downward flow, and negative values, upward flow. At values of x where the ordinates are negative, it may be said that the drains are not "draining" the soil. Four cases are shown. In each case the drain spacing is 40 ft, the drain depth 9 ft, and the artesian gravel at 50 ft. For I:r=1/2 ft, b=8 ft; II:r=1/4 ft, b=8 ft; III: r=1/2 ft, b=3 ft; IV: r=1/4 ft, b=3 ft. It is seen that for b=3 ft (curves III and IV) the land is "drained" for both r=1/4 ft and r=1/2 ft, but that for b=8 ft (curves I and II) the water penetrates through the surface of the soil both for r=1/2 ft and r=1/4 ft. When r=1/2 ft there is an undrained strip 12 ft wide midway between the drains and for r=1/4 ft the undrained strip is 16 ft wide. By taking x=a/2 in equation (40) and setting the left-hand side equal to zero, there may be obtained a general relation between b, h/2, a, d, and r giving the limiting condition for "drainage." Curves I, II, III, and IV may be considered as showing the rate of fall of the water-table at all points in completely waterlogged soil at the instant the layer of surface-water is of zero thickness and further surface-water is not supplied.

For curves I and II, at the instant in question, the water-table would tend to rise above the surface over a region 12 or 16 ft wide midway between pairs of drains. In curves III and IV the water-table would fall at all points.

Rate of fall of surface-water--If the surface of the soil has been flooded to a thickness t, and surface-water is not supplied to maintain this thickness, the water-level will fall and the rate of fall can be calculated. The calculation is made by equating the quantity of water M flowing in time dT vertically downward through a strip at the soil surface 1 cm wide and a units long, to the corresponding change in thickness dt of a section of the surface layer t units thick, having the same strip 1 cm wide and a units long as base. Thus,

$$MdT = adt$$

or, the rate of fall of the surface-water is

$$dt/dT = -M/a \quad \ldots\ldots (41)$$

where a minus sign has been used since t decreases as T increases.

The quanity M can be obtained in a number of ways. For example,

$$M = 2 \int_{x=0}^{x=a/2} (\partial U_n/\partial y)_{x=d}\, dx \quad \ldots\ldots (42)$$

where U_n is given by equation (32); or if there is no artesian water penetrating the surface of the soil

$$M/2 = [V_n]_{x=0} - [V_n]_{x=a/2}$$

where the V_n's are given by equation (38). In any event, M will be of the form

$$M = E + Ft$$

where E and F are involved constants of a, h/2, d, r, and b obtained from equation (42).

Substituting equation (42) into (41) and integrating

$$-\int dT/a = \int dt/(E+Ft)$$

or if T_1 is the time for the surface-water to fall from thickness t_0 to t_1

$$T_1 = (a/F) \log[(E+Ft_0)/(E+Ft_1)]$$

A mathematical identity--An interesting numerical check will now be obtained. Since the right-hand sides of equation (32) and (33) are equal, they may be equated, giving the expression,

$$8\pi q_n d(d-y)/ah + q_n \sum_{n=-\infty}^{\infty} \log[\cosh 2\pi(y-nh)/a - \cos 2\pi x/a]/[\cosh 2\pi(y-2d-nh)/a - \cos 2\pi x/a]$$
$$= q_k \sum_{k=-\infty}^{\infty} \log[\cosh 2\pi(x-ka)/h - \cos 2\pi y/h]/[\cosh 2\pi(x-ka)/h - \cos 2\pi(y-2d)/h$$

Now q_k and q_n are for practical purposes equal when r is small and are identically equal when r is infinitesimally small. Therefore, cancelling the q's in the above expression, putting the logarithmic terms on the right-hand side, multiplying both sides by ah/8πd(d-y), and taking n=k, there results the identity, valid at all points in the soil medium (but not inside infinitesimally small drains),

$$1 \equiv \frac{ah}{8\pi d(d-y)} \sum_{n=-\infty}^{\infty} \log \frac{[\cosh 2\pi(x-na)/h - \cos 2\pi y/h][\cosh 2\pi(y-2d-nh)/a - \cos 2\pi x/a]}{[\cosh 2\pi(x-na)/h - \cos 2\pi(y-2d)/h][\cosh 2\pi(y-nh)/a - \cos 2\pi x/a]}$$

or letting the quantity on the right hand side be A_0 for n=0; $A_{-1,1}$ for n=1 and n=-1; $A_{2,-2}$ for n=2 and n=-2; etc., there results

$$1 = A_0 + A_{1.-1} + A_{2,-2} + \cdots$$

To check the above identity the values d=10, a=50, h=50, that is, (h/2=25), y=0, and x=12.5 were substituted in the right-hand side and the calculations made. The results are

$$\begin{aligned} A_0 &= 1.0333\ 2467 \\ A_{1,-1} &= -.0332\ 6153 \\ A_{2,-2} &= -.0000\ 6299 \\ A_0 + A_{1,-1} + A_{2,-2} &= 1.0000\ 0015 \end{aligned}$$

the sum being unity to six places of decimals.

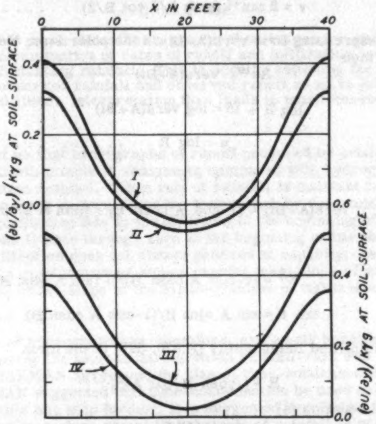

Fig. 3--Drainage rate at surface of soil (or rate of fall of water-table) as a function of the distance x from a vertical plane through the axis of the drain

Acknowledgments

The author wishes to thank S. W. HARDING and J. K. WOOD for the negatives used for Figure 2.

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APPENDIX I--Evaluation of log vers(A+Bi)

It is proved that if A and B are real constants, the complex potential

$$w = u+iv - \log \operatorname{vers} (A+Bi) \qquad (1)$$

yields

$$u = \log (\cosh B - \cos A) \qquad (2)$$

$$v = 2 \tan^{-1} (\tanh A/2 \cot B/2) \qquad (3)$$

The proof is obtained by expressing first vers(A+Bi) in the polar form $Re^{i\theta}$, where R is the modulus and θ the amplitude; then

$$Re^{i\theta} = \operatorname{vers}(A+Bi)$$

$$\log R + i\theta = \log \operatorname{vers}(A+Bi)$$

$$u = \log R \qquad (4)$$

$$v = \theta$$

Now [P:616]

$$\operatorname{vers}(A+Bi) = (1-\cos A \cosh B) + i(\sin A \sinh B)$$

so that by inspection

$$R^2 = (1-\cos A \cosh B)^2 + (\sin A \sinh B)^2 \qquad (5)$$

$$\tan \theta = \sin A \sinh B/(1-\cos A \cosh B) \qquad (6)$$

Equation (5) can be simplified immediately [P:570, 657] to the form

$$R = [(\cosh B - \cos A)^2]^{(1/2)}$$

from which with the aid of equation (4)

$$u = \log(\cosh B - \cos A) \qquad (2)$$

the first result sought. Equation (6) can likewise be simplified, but rather than simplifying it as it stands, it is easier to start again with equation (1), using $2 \sin^2(A+Bi)/2$ for vers(A+Bi). Thus, setting

$$R_1e^{i\theta 1} = \sin(A+Bi)/2 \qquad (6)$$

equation (1) may be written

$$w = u+iv = \log 2 \sin^2(A+Bi)/2 = \log 2(R_1e^{i\theta 1})^2 \qquad (7)$$

Expanding now the right-hand side of equation (6) [P:615]

$$\sin(A+Bi)/2 = \sin A/2 \cosh B/2 + i \cos A/2 \sinh B/2$$

from which by inspection

$$\tan \theta_1 = \cot A/2 \tanh B/2$$

that is,

$$\theta_1 = \tan^{-1}(\cot A/2 \tanh B/2)$$

But from equation (7)

$$iv = 2i\theta_1$$

so

$$v = 2 \tan^{-1}(\cot A/2 \tanh B/2) \qquad (3)$$

the second result sought.

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TIME-CONDENSATION IN HYDROGRAPH-ANALYSIS

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Abstract--This paper describes a graphical technique for analysis of hydrographs and the determination of rates of runoff and infiltration associated with intermittent or fluctuating rainfall. This is done by adjusting the time-scale of mass-curves of observed rainfall and observed runoff so as to provide straight or slightly curved lines. Interpretation then leads to mass-curves of detention and retention.

Experience has taught us that hydrographs of runoff produced by artificial rainfall, applied at a constant rate, are relatively simple to analyze as compared with hydrographs of runoff produced by fluctuating or intermittent rainfall. When rate of rainfall is constant from beginning to end of the storm, the analyst can work backwards on the hydrograph by determining the final rate of infiltration-capacity and by projecting this in the direction of the beginning of the storm with gradually increasing curvature, make it pass through zero at the beginning of the storm. In the case of natural rainfall, however, infiltration does not always proceed at capacity; consequently, the curve of actual infiltration will be a combination of slopes ranging from slope of mass-rainfall, during periods of low rate of rainfall, to the slope of the capacity-curve of infiltration during periods of excess of rainfall.

Analyses of this type of hydrograph are, therefore, extremely hazardous and laborious. It was for the purpose of eliminating the periods during which rainfall-rate was less than infiltration-capacity rate that L. K. SHERMAN introduced the idea of time-condensation [see 1 of "References" at end of paper]. SHERMAN suggested that time-condensation be used only during periods of low rate of rainfall. Taking this one step further, it is suggested herein that rainfall be compacted through time-condensation to such an extent that the rate of rainfall is constant throughout the storm, that is, the mass-curve is a straight line. The slope of this line (rate of rainfall, condensed) is not fixed, but can be any slope which represents at least the average of highest rainfall-rate for any period of approximately ten or more minutes. Condensation of mass-rainfall into this straight line is achieved by merely drawing the straight line as indicated (P, tc) on Figures 1, 2, 3, and 4.

Mass-runoff is plotted to the same condensed scale as rainfall by plotting various values of mass-runoff to the condensed scale immediately below the related value of mass-rainfall. For example, on Plot 63, Figure 1, mass-runoff at 22^h39^m was 1.79 inches and rainfall at that time was 2.48 inches. Therefore, on the condensed scale the value of runoff, 1.79 inches, is plotted directly below the 2.48 inch value of rainfall. The entire curve of mass-runoff can be thus condensed to the same time-scale as was rainfall.

The analyst will soon learn that it is necessary to condense only such points from the mass-runoff curve as occur during very low rates of runoff. This is true since it is only during periods of low or zero rates of runoff that surface detention is negligible, and consequently mass-runoff equals mass-rainfall minus retentions. If three or four such points at zero runoff-rate are obtainable, the curve of mass-rainfall minus infiltration and other retentions can readily and quite accurately be estimated by fitting a curve to these points and projecting it toward zero with gradually increasing curvature until it passes through zero at the beginning of excess of rainfall on the condensed scale. In instances of constant infiltration-capacity rate, no curvature will be needed or even be possible. This curve labeled [(P - R) tc] represents the curve of runoff which presumably would have pertained if the rain had fallen at this constant rate and no surface detention had occurred. In other words, it represents excess of rainfall.

The curve of (P - R) can be expanded to the normal time-scale by the exact reverse procedure from that indicated above. Using the condensed rainfall as a guide, whatever time-correction, plus or minus, is necessary in the condensed curve of rainfall to make it fit the actual rainfall-curve must also be made upon the corresponding values of excess of rainfall from the condensed scale. For example, on Figure 1 at the time that rainfall equals 2.88 inches we learn from a comparison of the curves (P,tc) and [(P - R) tc] that excess of rainfall equals 2.12 inches; consequently, in the

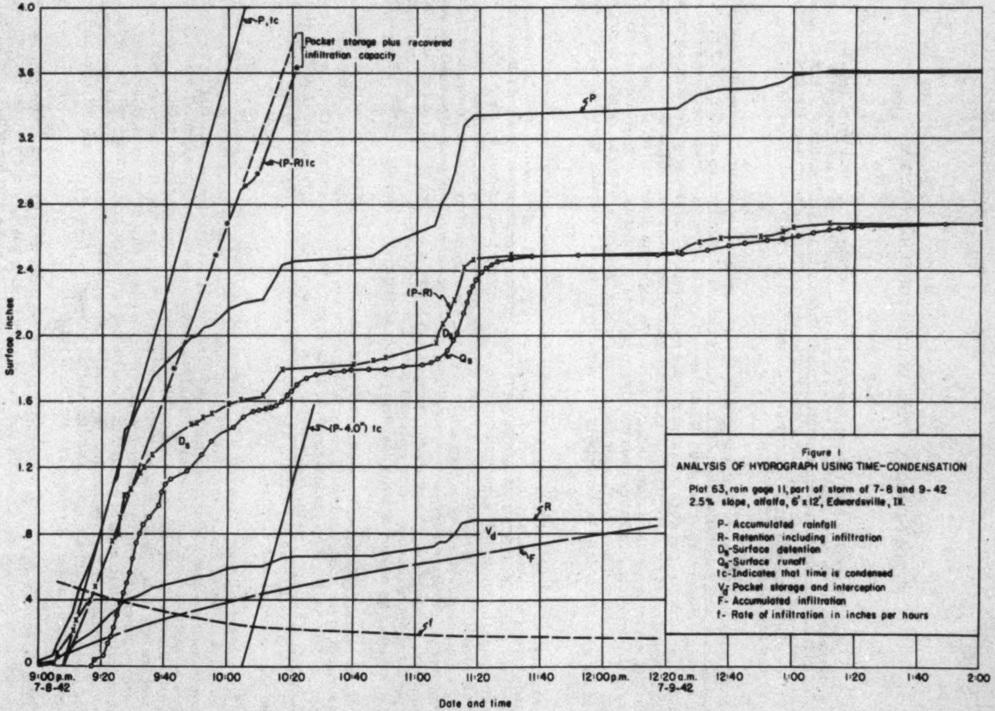

Figure 1

ANALYSIS OF HYDROGRAPH USING TIME-CONDENSATION

Plot 63, rain gage 11, part of storm of 7-8 and 9-42
2.5% slope, alfalfa, 6' x 12', Edwardsville, Ill.

P- Accumulated rainfall
R- Retention including infiltration
D_s-Surface detention
Q_s-Surface runoff
tc-Indicates that time is condensed
V_d-Pocket storage and interception
F- Accumulated infiltration
f- Rate of infiltration in inches per hours

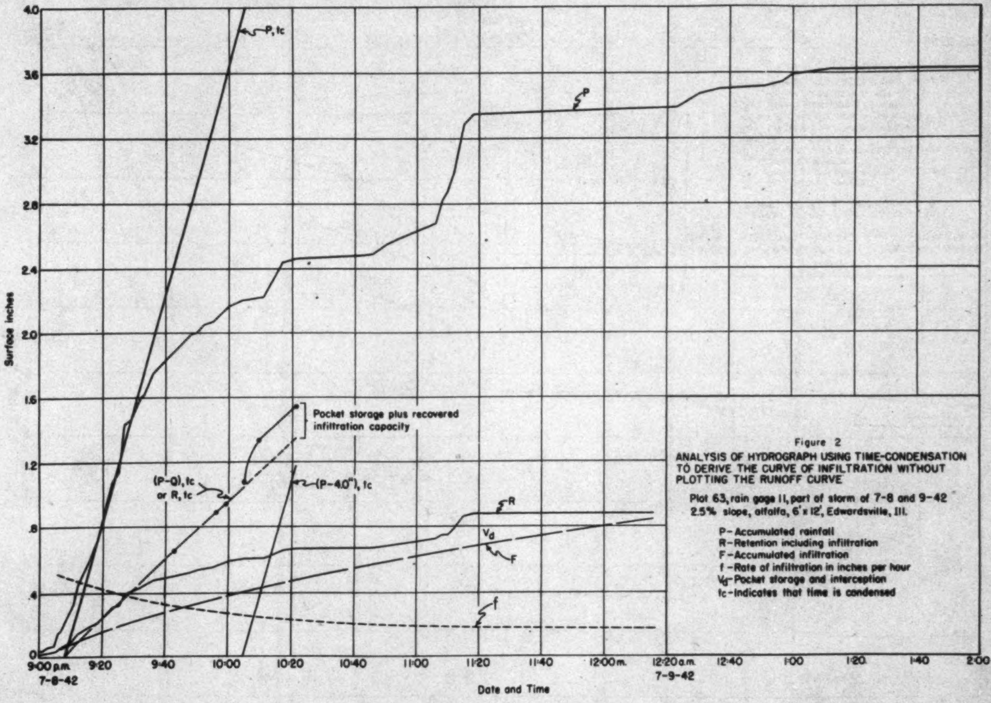

Figure 2

ANALYSIS OF HYDROGRAPH USING TIME-CONDENSATION TO DERIVE THE CURVE OF INFILTRATION WITHOUT PLOTTING THE RUNOFF CURVE

Plot 63, rain gage 11, part of storm of 7-8 and 9-42
2.5% slope, alfalfa, 6' x 12', Edwardsville, Ill.

P - Accumulated rainfall
R - Retention including infiltration
F - Accumulated infiltration
f - Rate of infiltration in inches per hour
V_d - Pocket storage and interception
tc - Indicates that time is condensed

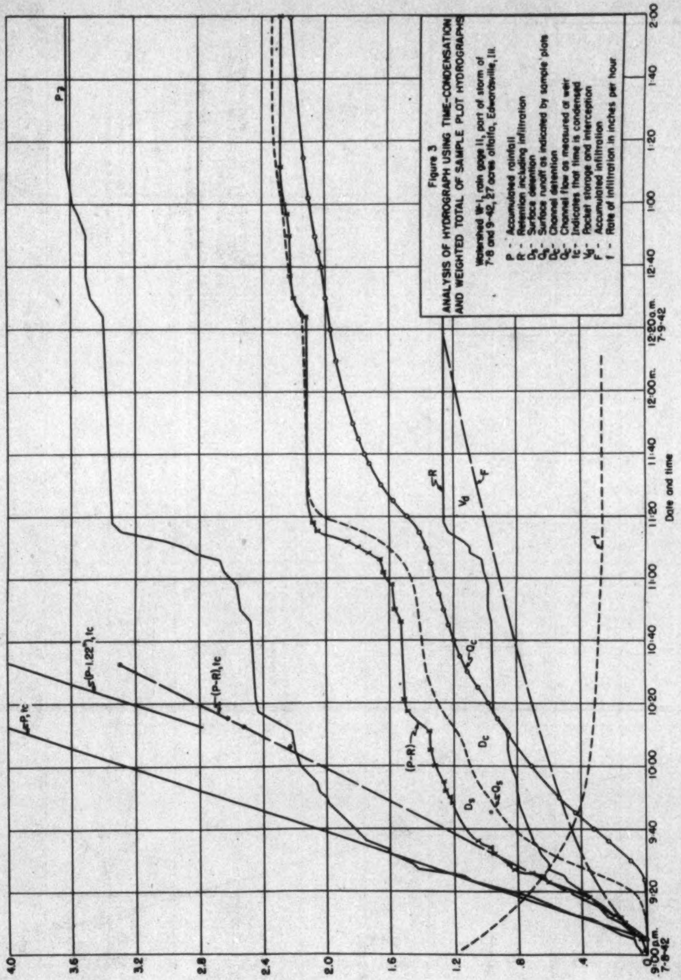

Figure 3

ANALYSIS OF HYDROGRAPH USING TIME-CONDENSATION AND WEIGHTED TOTAL OF SAMPLE PLOT HYDROGRAPHS

Watershed W-I, rain gage II, part of storm of 7-8 and 9-42, 27 acres alfalfa, Edwardsville, Ill.

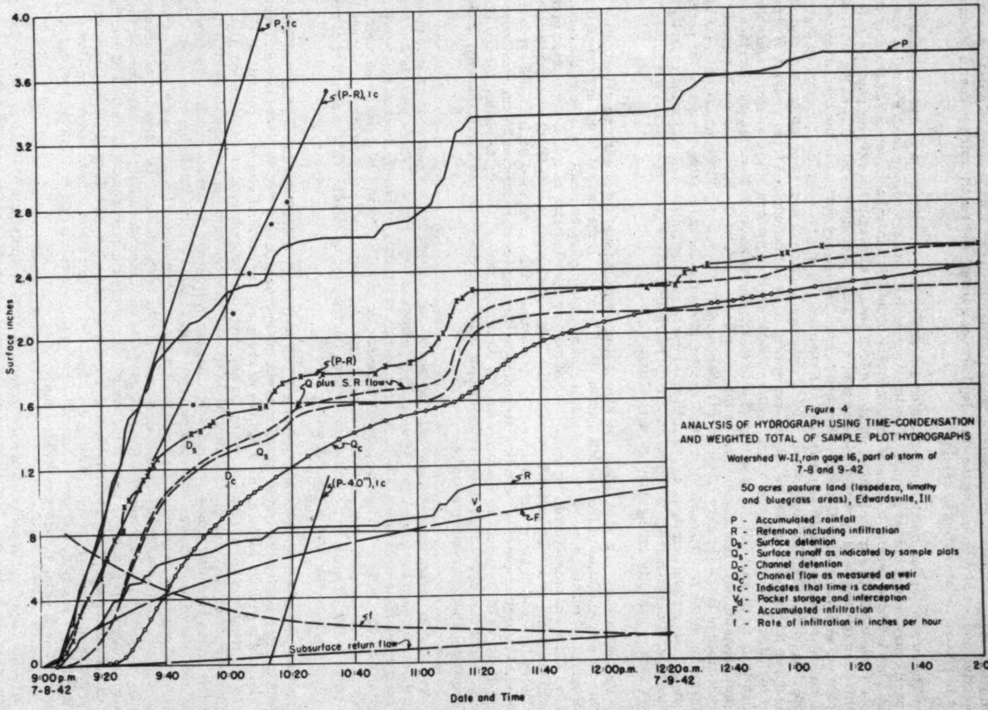

Figure 4

ANALYSIS OF HYDROGRAPH USING TIME-CONDENSATION AND WEIGHTED TOTAL OF SAMPLE PLOT HYDROGRAPHS

Watershed W-II, rain gage 16, part of storm of 7-8 and 9-42

50 acres pasture land (lespedeza, timothy and bluegrass areas), Edwardsville, Ill.

actual scale we plot (P - R) equal 2.12 inches at $23^{h}05^{m}$, the time at which rainfall equaled 2.88 inches. At no point should the (P - R) -curve drop below the curve of Q. Such an occurrence would indicate improper location or curvature of the [(P -R) tc]-curve. This procedure constitutes an objective method of eliminating the time-lag between rainfall and runoff which is due to detentions and is related to intensities of rainfall.

The first objection which comes to mind concerning time-condensation is that the infiltration-capacity may change during periods of little or no rainfall. It does appear from Figure 1, and other trials not included herein, that there is a recovery of infiltration-capacity which occurs only during those periods of little or no rainfall which are long enough to permit the existing capacity-rate of infiltration to dispose of pocket storage as well as to drain partially the porosity of the surface layers of the soil-profile. However, any such occurrence is very obvious in the condensed scale; the excess-rainfall curve (P - R) will tend to flatten out and will then resume the same or a greater slope, than pertained previously, when rainfall resumes at rates in excess of infiltration-capacity. The upper three points on the [(P - R) tc]-curve (Fig. 1), were determined from a series of showers (not included in the hydrograph) which occurred subsequent to periods of two or more hours during which little or no rain fell. It is worthy of note that the plots known to have the least surface or pocket retention have the smaller jogs in this condensed curve of (P - R). This would indicate that pocket storage is the primary factor in this phenomenon. Curves of infiltration are obtained by subtraction of the (P - R)-curve from the P-curve, plotted as R, and making allowance for pocket storage as described below, using the condensed curve as substantiation of estimated capacity pocket-storage. Pocket-storage would be an initial abstraction on the condensed scale, but it may vary from zero to capacity during intermittent rainfall.

Figure 2 (which is a work-sheet for Fig. 1) illustrates the method of deriving actual infiltration without a determination of the rainfall-excess (P - R)-curve. If the analyst is not interested in the hydrograph of runoff, he need not even plot it. Rainfall is plotted as usual and also to the condensed scale. Values of mass-runoff during periods of zero or very low rate of runoff are plotted to the condensed scale as a subtraction from rainfall. The resulting curve [(P - Q) tc] represents retention including infiltration for various values of mass-rainfall on the condensed scale. This curve is expanded to the actual curve of retention according to the dictates of expansion for the condensed rainfall-curve to the actual in a manner exactly similar to that previously described for the (P - R)-curve. Since this curve represents retentions, it must be divided into two parts; namely, pocket-storage (V_d) and mass-infiltration (F).

The best criterion upon which to base the shape and position of the F-curve is an assumption that V_d must reach the same capacity during all periods of peak-runoff. These periods can easily be recognized from the slope of the pertaining section of rainfall or runoff. Pocket-storage will be partially or wholly depleted during periods of lesser or no rate of runoff in instances of appreciable rates of infiltration, but may, on the other hand, in cases where the rate of infiltration is very low (F-curve is flat), remain at capacity even beyond the duration of runoff. This is a matter of careful observation on the part of the analyst.

In applying this method to watersheds W-I and W-II (Figs. 3 and 4), it is apparent that we can expect greater success on larger areas wherein the hydrograph is not so sensitive to small irregularities of the ground-surface. As a method of checking, the curve of excess of rainfall (P - R) is derived through the use of time-condensation and represents supply to surface-detention (D_s), channel-detention (D_c), and channel-flow (Q_c). To estimate the curve of overland-flow (Q_s) (that is, rainfall minus retention minus surface-detention) the hydrograph of surface runoff is derived as a weighted total of hydrographs observed on small sample plots located within the watershed. This hydrograph represents overland-flow and must supply channel-detention and channel-flow. Channel-flow (Q_c) was measured by means of a rated weir during these storms. The sensible adherence of the Q_s-curve to a path between (P - R) and Q_c for this and other storms tried speaks for the validity of the sample hydrographs as well as for the validity of the time-condensation method of determining excess of rainfall. It is regrettable that in the case of W-II return-flow of subsurface water contributes to channel-flow thus causing discrepancies. The rate of subsurface return-flow was estimated as a constant, and was added to the curve Q_s; the results as noted in the hydrograph for Watershed W-II (Fig. 4), are well within reason.

The above method of analysis of hydrographs is directly applicable to those numerous cases in which complete data of the rainfall-phenomenon are available but only two or three points on the mass-curve of runoff are available. The curve of excess rainfall and/or retention can apparently be quite accurately derived. The derivation of actual runoff (either overland-flow or channel-flow) would be dependent upon the validity of depth-discharge data for each type of flow. We feel that at least in the case of overland-flow we can expect a high degree of success by using depth-discharge relationships as determined with the F-type infiltrometer. Very little information is at hand concerning the depth-discharge, or rather the [channel-storage - channel-flow]-relationship of larger areas, but perhaps through applications of thfs method to watershed-data some idea of this relationship could be obtained even though overland-flow had to be estimated through the use of empirically derived depth-discharge relationships.

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DISCUSSION

L. K. SHERMAN (Oak Park, Illinois, September 1, 1945)--This paper refers to the art of deriving a complete curve of infiltration-capacity from intermittent or separated rainfalls. A complete f-curve is formed only when rain, at capacity, or greater rates, falls upon a dry soil-section and continues without interruption until the ultimately constant infiltration-rate, f_c, is reached. Such an f-curve is perfectly smooth and its time-base is the same as the duration of the rain. If the rain ceases for a short time (say one hour or less), or falls below capacity-rate, then the f-curve time will be less than the total rain-duration. In order to derive a smooth f-curve, time condensation must be applied by some method like SHERMAN'S or the graphical method here given by HOLTAN.

Now let us consider lulls longer than one hour. In paragraph six, HOLTAN discusses the fact that infiltration-capacity may change radically during a lull or rainless interval. The practical importance and reason for this phenomenon has not been appreciated until recently.

Several years ago W. W. HORNER noted that f-curves, obtained from a series of rains, did not plot as arcs of a complete curve. The partial f-curves started above the complete curve, dropped rapidly and finally coincided with the complete curve.

FREE, BROWNING, and MUSGRAVE [Tech. Bull. No. 725, U. S. Dep. Agric.] give numerous experiments showing the rise of infiltration-capacity following the period of 24 hours between the "dry" run and the "wet" run. From these data, the writer [Trans. Amer. Geophys. Union, Part I, p. 57, 1944] shows a typical case. The infiltration-rate fell to 1.5 inches per hour during the three-hour dry run. At the resumption of rain, 24 hours later, the infiltration-rate started at 3.6 inches per hour (iph) falling to 1.5 iph in 25 minutes. At 60 minutes this "wet" run f-curve coincided with a complete f-curve for the remainder of the three-hour wet run. f_c was 0.82 iph.

The reason for all of this, by the hypothesis of B. S. BARNES is: "Infiltration is governed by two properties of the soil (including cover): Capillary and non-capillary porosity. When the penetration of non-capillary or gravity-water has satisfied the demands of the capillary porosity of the soil-column, then all further infiltration is gravity-water at the rate of f_c." [See Trans. Amer. Geophys. Union, Part I, p. 57, 1944.]

The discussor is of the opinion that HOLTAN'S procedure of time-condensation enables the hydrologist to utilize several rain-observations, or partial f-curves, for the derivation of a complete and true curve of infiltration-capacity. He is now of the further opinion that the procedure for deriving composite or average f-curves, by assembling the partial f-curves at some fixed value of f, is fundamentally wrong. It has served, however, as a practical makeshift until the discovery of something better.

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(See also pp. 338, 357, 366, 378, 388, 392, and 450)

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SOME EFFECTS OF RAINDROPS AND SURFACE-FLOW ON SOIL EROSION AND INFILTRATION

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This presentation summarizes the findings from a number of experiments in which the effects of raindrop-impacts and the flow of surface-water on soil-erosion and infiltration were studied. Some implications drawn from this work are discussed. Many of the experiments were exploratory in nature, and many of the data have only qualitative significance.

The effects of impact of raindrops and of surface-flow on the surface-soil will, among other things, depend on the kinetic energy of the water in motion. Energy factors in rainfall and runoff were controlled for these experiments, and some of the effects of variations in energy were observed.

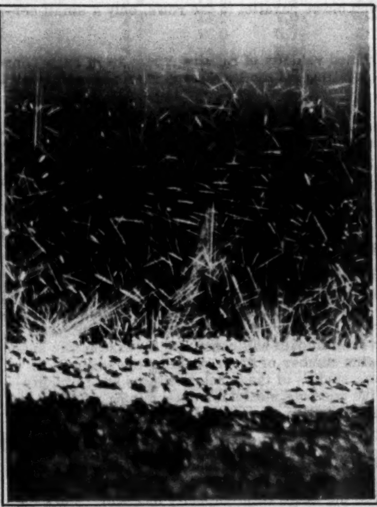

Fig. 1--A close-up view of raindrop striking the surface of the soil and the resulting splash

The subject matter has been divided into three parts, as follows: (1) raindrops (their energy and their effects on erosion and infiltration), (2) surface-flow (its energy and its effects on erosion and infiltration), and (3) some effects of raindrops and surface-flow applied together.

Raindrops

Energy of raindrops--When raindrops strike the surface of the soil (Fig. 1), they break down the clods and aggregates, and this separation of the particles develops a single-grain structure in the soil. The extent to which the clods and aggregates are broken down, the numbers of particles separated, and the transportation of soils in the erosion process are functions of the energy of the raindrops. For these reasons, the energy of raindrops, the effects of this energy on the soil, and how it may be effectively dissipated and the ill consequences of erosion by raindrops avoided, are matters of great interest to the soil conservationist.

The kinetic energy of a single raindrop is proportional to the product of its mass and the square of its velocity. Sizes and velocities of raindrops have been a subject of investigation for the past 50 years. J. OTIS LAWS [see 1 and 2 of "References" at end of paper] and J. OTIS LAWS and D. A. PARSONS [3], who started their raindrop-studies about 1937, seem to have been the first investigators to stress the wide variations in erosion and infiltration which are associated with variations in energy of the falling drops.

NICHOLS and GRAY [4], commenting on raindrop energy, stated, "Erosion is initiated by the great force of raindrops as they strike the surface soil. The total force expended by heavy rain is tremendous. J. OTIS LAWS (according to unfinished data) calculates that the velocity of falling rain is 20 mph. Two inches of rain on an acre then would have 194,900,000 foot-poundals, or 6,000,000 ft-lb of kinetic energy." They add that this is enough energy to raise a seven-inch layer of soil three feet. Quoting further, "Fortunately this terrific energy is dispersed both from point of time and space, but it still is extremely important. If the soil is exposed, it may be packed by this force and, if in condition to be eroded, some of it is churned into suspension. The heavier parts are left by settling, but the finer portions are carried away by water."

The energy of a raindrop can be calculated if its size and velocity are known. But it is more difficult to calculate the total energy of a storm. LAWS has suggested dividing the rainfall into a number of different drop-sizes, and combining all drops of approximately equal size into one group. The average diameter and average velocity of the group would then be used to calculate the total energy of all drops in the group. The total energy of the storm would be the sum of the energies in the separate size groups.

In soil- and water-conservation work, principal interest lies in determining the energy of drops that strike the soil. This may be a different problem from that of calculating total energy of rainfall. Some of the drops are intercepted by plant residues and stones on the surface of the soil, while others may be intercepted by the growing vegetation. The vegetal canopy may change between storms and this complicates the problem of comparing the effects of one storm with those of another. Often without change in the canopy, different amounts of interception will occur with different storms. For example, an open canopy of tall vegetation may intercept more than 90 per cent of the raindrops if a high wind drives them in at an angle with the vertical. The same canopy may intercept less than 50 per cent of the drops if they fall vertically. In drilled crops with open canopies the direction of wind may affect the raindrop impact on the surface of the soil. If the wind blows across the rows, most of the drops may be intercepted, but if the wind blows parallel to the rows, only a small percentage of the drops may be intercepted.

If the crop canopy is closed, differences in size and velocity of raindrops may be of little consequence. Under these conditions the energy of drops falling off the leaves and stems of plants will be the more important consideration.

It is apparent that there will be no fixed relationship between the energy of raindrops and that of storm-impact on the surface of the soil in fields which have growing crops or where there is mulch on the surface. This leads one to believe that the problem presents research with at least two major tasks. The first will be to determine total energy of the rainfall and to devise ways for recording it. This will be the energy potentially available for destruction of bare soils. It is the energy which may accelerate soil erosion, cause sealing of the soil surface, cause water needed by crops to be wasted, and accelerate flood runoff. A complete evaluation of its seasonal and geographical variations would be helpful in making conservation programs more effective.

The second part of this research problem is that of determining how much of this energy is dissipated on the soil during each storm. It will probably have to be measured for each separate storm. As a result of some experimental work at Coshocton, Ohio [5], the writer suggests that this energy may be measured indirectly, by measuring the soil carried in the raindrop splash. This method is suggested by the fact that an increase in drop impact will cause an increase in the amount of soil carried by the splash. Also, an increase in the number of drops striking the soil will increase the amount of soil splashed. Results of some studies of these relationships are to be presented later, but the method is suggested here as one possible means for determining relative amounts of energy of the water-drops which are dissipated on the surface of the soil during rainstorms.

Effects of raindrop energy on eroding bare soils--The erosion process is started when raindrops strike the surface of the soil and break down the clods and aggregates. This is also the beginning of the surface-sealing process which reduces the infiltration-capacity of a soil. Since the erosion and surface sealing start with raindrop-impact, research in problems of erosion and infiltration must also start here.

McCALLA [6] experimented with water drops breaking down soil aggregates. He caused drops to be released one at a time from a height of 30 centimeters and to fall onto a single aggregate of 0.15 gram. He reported that from 4 to 323 drops of 4.7 mm diameter were required to break down various aggregates to a degree of fineness that it would pass through a one mm screen. Differences in the number of drops required to destroy the different aggregates corresponded with differences in soil properties.

McCALLA'S studies represent a very important contribution. They show that stability of aggregates under raindrop-impacts may vary greatly for different soils. However, considerably more work along these lines is needed and there is a great need for data which will show the effects of these aggregate differences on watershed performance.

In the studies of aggregate breakdown carried on at Coshocton, Ohio [5], the experimental techniques weredifferent from those used by McCALLA. In these studies, soil plots five by six feet were exposed to artificial rainfall. Rainfall intensity, drop-size, and drop-velocity were controlled as independent variables, and varied one at a time. The soil was eroded Muskingum silt-loam. Its aggregation was determined before rainfall was applied. During rainfall the percentages of the different aggregate sizes (including stone fragments) carried in the raindrop splash and those transported by the runoff were determined, and following rainfall aggregate determinations were made of the surface soil. Results of these tests are shown in Tables 1, 2, and 3. All aggregate determinations were by the YODER wet-sieve method, so that the changes in percentages of different aggregate sizes should not be affected by slacking. In other words, analysis of the original soils showed the aggregation after slacking and treatment on the wet-sieve, and in view of this, analysis of samples following raindrop impact should reflect only the effects of drop impacts in breaking down soil aggregates.

Table 1--Aggregate analysis of soil materials contained in raindrop splash

Raindrop size	Height of fall	Velocity	Size of grain, in mm >2	1 - 2	0.5 - 1	0.25-0.5	0.105-0.25	<0.105
mm	feet	fps	pct	pct	pct	pct	pct	pct
5.1	6.7	19.2	2.40	3.89	5.07	5.24	11.38	71.98
5.1	3.9	15.0	1.41	3.68	4.98	5.12	11.53	73.25
5.1	2.3	12.0	1.04	2.87	5.74	6.56	12.11	71.65
3.5	6.7	18.0	0.74	2.87	5.24	6.65	10.83	73.66
3.5	3.9	14.5	0.94	2.81	5.66	5.85	10.81	73.91
3.5	2.3	12.0	0.44	2.31	6.25	8.22	13.86	68.89

Table 2--Aggregate analysis of soil materials contained in runoff

Raindrop size	Height of fall	Velocity	Size of grain, in mm >2	1 - 2	0.5 - 1	0.25-0.5	0.105-0.25	<0.105
mm	feet	fps	pct	pct	pct	pct	pct	pct
5.1	6.7	19.2	0.40	1.68	2.39	2.85	5.27	87.26
5.1	3.9	15.0	0.41	0.91	1.71	2.25	6.25	88.45
5.1	2.3	12.0	0.61	0.56	1.27	1.55	3.95	92.04
3.5	6.7	18.0	0.47	1.13	1.99	2.14	6.03	88.21
3.5	3.9	14.5	0.08	0.66	1.35	1.91	3.02	92.88
3.5	2.3	12.0	0.23	0.80	1.47	1.41	3.64	92.43

Table 3--Aggregate analysis of original soil materials and of those scraped from surface of plot following rainfall

Raindrop size	Height of fall	Velocity	Size of grain, in mm >2	1 - 2	0.5 - 1	0.25-0.5	0.105-0.25	<0.105
mm	feet	fps	pct	pct	pct	pct	pct	pct
Original material			13.34	6.33	6.69	8.01	12.05	53.55
Soil material scraped from surface following rainfall								
5.1	6.7	19.2	19.85	4.38	4.47	4.09	12.62	54.56
5.1	3.9	15.0	22.13	5.52	4.33	3.47	7.89	56.62
5.1	2.3	12.0	18.91	4.53	4.62	3.92	7.61	60.37
3.5	6.7	18.0	18.32	4.77	4.32	4.17	10.23	58.16
3.5	3.9	14.5	19.45	5.11	4.63	3.89	10.07	56.36
3.5	2.3	12.0	25.29	4.15	3.39	3.29	7.12	56.73

The quantities of soil carried by raindrop-splash were also determined in the above experiments, and it was found that these were very sensitive to small changes in either drop-size or velocity. They are also affected by rainfall intensity. These data are shown in Table 4. In this table the values of E represent grams of soil intercepted in splash samplers during a 30-minute period. The best-fitting relationship for these data was found to be $E = K V^{4.33} d^{1.07} I^{0.65}$, where V = velocity of drops in feet per second, d = diameter of drops in millimeters, I = intensity of rainfall in inches per hour, and K = a constant. The value of K will depend on numbers and types of samplers used, and it will be different for different soils.

Table 4--Quantities of soil contained in raindrop-splash for various values of d, I, and V

Drop-size, d = 3.5 mm				Drop-size, d = 5.1 mm			
Exp	V	I	Avg.	Exp	V	I	Avg
	fps	iph	gr		fps	iph	gr
A	18.0	4.8	223	M	19.2	4.8	446
B	18.0	6.6	245	N	19.2	6.6	543
C	18.0	8.1	368	P	19.2	8.1	690
D	18.0	14.8	492	Q	19.2	14.8	786
E	14.5	4.8	67.1	R	15.0	4.8	203
F	14.5	6.6	96.3	S	15.0	6.6	233
G	14.5	8.1	138	T	15.0	8.1	295
H	14.5	14.8	232	U	15.0	14.8	329
I	12.0	4.8	15.3	V	12.0	4.8	35.7
J	12.0	6.6	20.5	W	12.0	6.6	61.7
K	12.0	8.1	33.2	X	12.0	8.1	67.3
L	12.0	14.8	47.8	Y	12.0	14.8	157

If the relationships between rainfall-characteristics and quantities of soil splashed can be established for different conditions of bare soils, then it may be that the difference between the splash which would occur on a bare soil, and that which actually occurs when the soil is partially protected by a mulch, may be used as a measure of the effectiveness of the mulch in protecting the soil. The effectiveness of some crop-canopies may be evaluated in like manner. This type of experiment has not yet been tried on a field basis, but the large changes in quantities of soil carried by raindrop-splash and which are caused by changes in raindrop-characteristics, would encourage such experimentation.

From a study of Table 4, one may conclude that the principal effects of small changes in raindrop-velocity and size will be to increase the number of particles of soil set in motion by impact, and this would increase the number of aggregates destroyed. Tables 1, 2, and 3 show that the degree of fineness to which each of the aggregates is broken may not be affected to an appreciable extent by changes in drop-size, drop-velocity or intensity of rainfall. Therefore, the principal effects of changes in rainfall characteristics may be to change the rate at which aggregates are destroyed.

Rates of splash-erosion for different periods of rainfall-duration are shown in Figure 2. These rates were measured on an eroded Muskingum silt-loam soil, using artificial rainfall. The soil was air-dry at the start of each experiment, and the first raindrops striking the surface tended to break down aggregates and release fine particles of silt and clay. The splash carried some of these particles and when it returned to the surface, it was no longer clear water as was the original raindrop. Instead, it was composed of a mixture of water, clay, silt, and sand. As returning splashes infiltrated, most of the splashed particles of sand and silt were deposited on the surface, but the clay-particles were mostly filtered out immediately below the surface, as the water percolated downward through the soil-mass. These deposits of fines contributed to the surface-sealing process which was well advanced within two to three minutes after the beginning of rainfall. The rate of splash-erosion, which reached a maximum at about this time, seemed to be caused by the loose material on the surface being covered with water, with very little cohesion between the particles. Reductions in rates of soil-splash which follow about three minutes after the beginning of rainfall (see Fig. 2), were associated with the removal of these loose materials from above the plane of sealing.

Since the relationship $E = K V^{4.33} d^{1.07} I^{0.65}$ shows the relative amounts of soil splashed by the impact of raindrops, it should also express the relative degree of muddiness of the surface-water outside the channels. This water is the runoff moving in pre-channel stages and the soil that it transports should be proportional to the splash erosion. This phase of the problem has not been investigated very thoroughly, but it will be shown later that in several experiments the soil-content of the runoff was found to be proportional to the amount of soil carried by raindrop-splash. This means that the soil carried by raindrop-splash will be proportional to the soil-loss measured in runoff unless there is either (1) active rill and gully erosion which further increases soil-concentration in the runoff, or (2) deposits of soil before samples of runoff are taken. The energy which causes rill and gully erosion is primarily a function of surface-flow, whereas the energy which causes pre-rill erosion (sheet-erosion) is primarily a function of raindrop-impact.

It was found that the sizes of particles carried by raindrop-splash and the distances they would be carried depended on the sizes and velocities of the drops. When using a drop-size of 5.1 mm and a drop-velocity of 18 fps, the maximum horizontal distance that the splash carried soil was five feet. Some stone fragments as large as four mm were splashed eight inches, and soil aggregates and particles of two mm were carried as far as 16 inches.

In a second experiment, drop-size was reduced to 3.5 mm, and this change reduced the drop-velocity to about 17 fps. Under this rainfall the maximum distance particles were splashed was about 3.5 feet, and some soil-aggregates and stone-fragments of 2 mm were carried as far as eight inches.

On level surfaces the outgoing splash would normally be replaced by incoming splash, but it was found that on a 10 per cent slope, 3.1 times as much soil was caught by the samplers which intercepted the splash moving down slope, as was caught by those which intercepted the splash moving in uphill directions. These experiments were made in the absence of wind. The splashes resulting from impact which carry the soil into the air are small and light, and wind might carry them long distances. It is believed that very appreciable amounts of soil are moved down-slope by raindrop-splash on bare soils, and that these losses may be greatly increased when the rainfall is accompanied by a strong wind blowing in downhill directions.

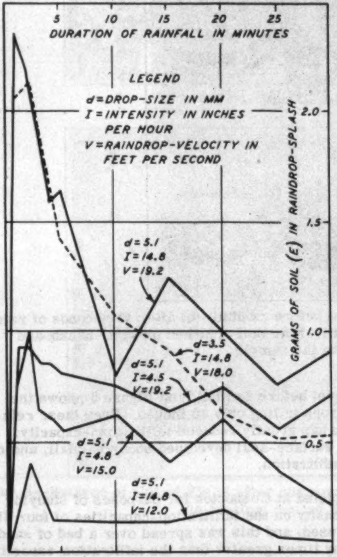

Fig. 2--Soil in raindrop-splash plotted against time

Figure 3 shows the effects of splash when there is no return splash to replace the soil carried away. The loss shown in this figure resulted from about eight inches of artificial rainfall of 75 minutes duration, with drops of 5.1 mm falling from a height of 6.7 feet. Note the columns of soil standing under the metal discs.

The effects of raindrop-impact are of greatest importance in soil and water-conservation work. Investigations of the magnitude of drop-impacts which are associated with natural storms, their effects on the soil, and the effectiveness of different crops and tillage practices in dissipating this energy and thereby conserving soil are matters of greatest importance to both the hydrologist and the soil conservationist. The above experiments demonstrate one method which can be used for measuring the erosion produced by impact of the raindrops. The same procedures may be used for evaluating the effectiveness of some crops and tillage practices in protecting the soil against erosion by falling raindrops.

Effects of raindrop energy on infiltration--When raindrop-impacts break down the aggregates they splash the soil-particles into the surface-water to make it muddy, and they cause puddling and compaction. Each one of these actions tends to destroy the infiltration-capacity of the soil. The term infiltration-capacity as used in this paper denotes maximum rates, expressed in inches per hour, at which water will pass through the least permeable plane of the surface of the soil. Where soils are exposed to raindrop-impact, this least permeable plane will be found in the surface-seal which is formed. LAWS [1] reported, "It was found that as the drop-size increased, the infiltration rate decreased by as much as 70 per cent." BORST and WOODBURN [7] reported similar results when they eliminated most of the drop-impact with straw supported an inch above the soil. Many investigators have pointed out that mulches and crop-canopies which protect the surface of the soil against raindrop-impact will help to preserve its infiltration-capacity.

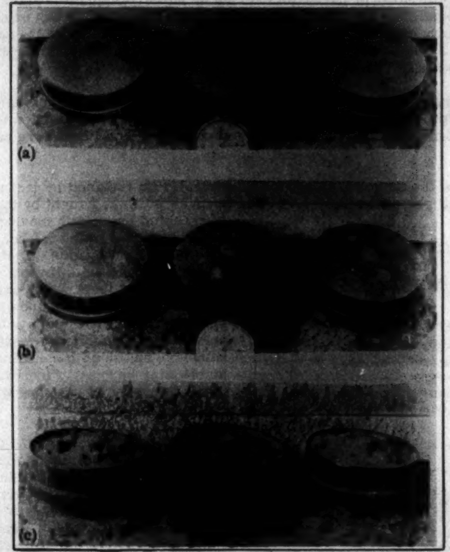

Fig. 3--Soil sample with metal disks on surface; (a) before rainfall; (b) after 45 seconds of rainfall; (c) after one hour and 15 minutes of rainfall. Note soil splashed on white backboard six inches from the sample

Figure 4 shows the surface of an experimental plot before rainfall, and Figure 5 shows the same plot after one hour of artificial rainfall with drops falling only 20 inches. Even these relatively low drop-velocities developed a surface which has greatly reduced infiltration-capacity. DULEY and KELLY [8] photographed a section of a surface-seal developed under rainfall, and concluded it was the most outstanding factor affecting infiltration.

Twenty-nine infiltration experiments were completed at Coshocton for purposes of studying the effects of drop-size, drop-velocity, and rainfall-intensity on the infiltration-capacities of four different soils. A layer of soil 1-1/2 inches deep was used, and this was spread over a bed of sand which was known to have a percolation-capacity many times greater than the infiltration-capacity of the layer of soil which was to be tested. Artificial rainfall was applied at a rate greater than the infiltration-capacity of the soil, and under these conditions the rates of infiltration would be limited only by the capacity of pores of the soils. These capacities were greatly reduced as the surface-seal developed. The results listed in Table 5 show quite conclusively that a variation in either drop-size or drop-velocity will cause a change in the infiltration-capacity of the soil. Changes in drop-velocity have greatest effect, changes in drop-size are second, and changes in rainfall-intensity are least effective.

Many difficulties are encountered when one attempts to relate variations in rainfall-energy to their effects on the soil. Some of these are due to partial interception of rainfall which may vary with each storm. Some of the problems encountered in applying rainfall-energy data when there is some interception were discussed previously, under the sub-heading of Effects of raindrop energy on eroding bare soils. These same difficulties will be encountered in an attempt to relate the energy of rainfall to its effects on infiltration.

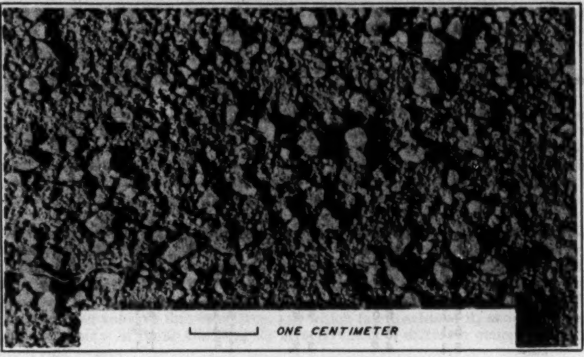

Fig. 4--Surface of a plot before rainfall

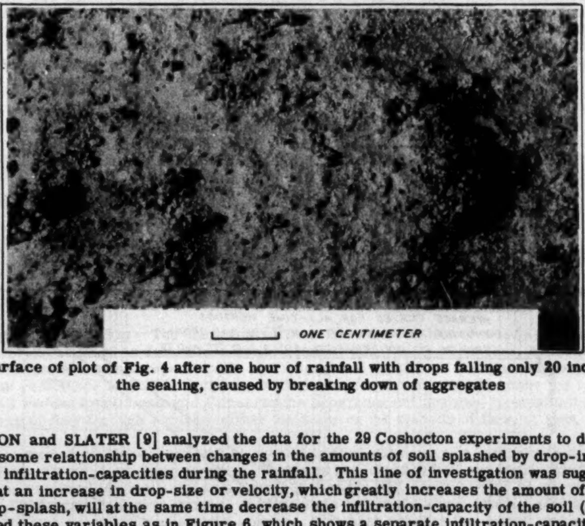

Fig. 5--Surface of plot of Fig. 4 after one hour of rainfall with drops falling only 20 inches. Note the sealing, caused by breaking down of aggregates

ELLISON and SLATER [9] analyzed the data for the 29 Coshocton experiments to determine if there was some relationship between changes in the amounts of soil splashed by drop-impact, and changes in infiltration-capacities during the rainfall. This line of investigation was suggested by the fact that an increase in drop-size or velocity, which greatly increases the amount of soil carried by raindrop-splash, will at the same time decrease the infiltration-capacity of the soil (see Table 5). They plotted these variables as in Figure 6, which shows a separate infiltration-capacity curve for each different soil type. The capacity of each soil is shown to be sensitive to the quantities of soil-splash which were computed by the splash-erosion formula. These trends suggest that the amount of soil carried by the splash may serve as a basis for estimating decreases in infiltration-capacities that are caused by raindrop impact.

The relation of soil-splash to reductions in the infiltration-capacity shown in Figure 6, is an average value for all time-periods shown in Table 5. For a given amount of soil-splash (say ten grams) there will be a reduction in the infiltration-capacity. It may be that this reduction is not greatly affected by rate of splash and that the reduction will be of about the same magnitude whether the ten grams of splash occur over ten or 30 minutes. There is some evidence of this, but the

Table 5--Summary of infiltration data

Test	Soil	Drop velocity	Drop diameters	Rainfall intensity	Infiltration rate for rainfall durations of 5 min	15 min	30 min	1 hr	Grams of soil in splash (E)
		fps	mm	iph	iph	iph	iph	iph	gm/30 min
1	II	0	5.1	6.5	4.0	3.7	3.4	3.1	0
2	II	0	5.1	6.7	3.5	3.2	3.0	2.8	0
3	II	10.2	5.1	6.4	1.8	0.7	0.6	0.6	34.1
4	II	20.4	5.1	5.8	1.4	0	0	. .	643
5	III	0	5.1	6.8	. .	. .	. .	6.7	0
6	III	3.1	5.1	4.3	. .	. .	3.4	2.6	0.2
7	III	3.1	5.1	6.9	5.7	4.6	3.5	2.7	0.2
8	III	3.1	5.1	11.4	6.1	4.3	3.5	3.0	0.3
9	III	3.1	3.5	4.4	. .	4.2	3.5	2.7	0.1
10	III	3.1	3.5	6.6	. .	5.1	3.8	2.8	0.1
11	III	6.1	5.1	6.5	4.9	2.7	2.1	2.0	3.7
12	III	10.2	5.1	3.3	. .	1.4	1.0	0.8	22
13	III	10.2	5.1	4.7	3.2	1.5	1.1	1.0	28
14	III	10.2	5.1	4.7	3.6	1.5	1.1	1.0	28
15	III	10.2	5.1	6.7	2.0	1.0	.7	. .	35
16	III	10.2	5.1	6.9	2.4	1.3	1.2	. .	36
17	III	10.2	5.1	12.1	2.1	.8	. .	. .	52
18	III	10.2	3.5	4.7	3.5	1.5	1.2	1.0	19
19	III	10.2	3.5	6.8	3.4	1.4	1.3	. .	24
20	III	10.2	3.5	6.8	2.6	1.6	1.4	1.3	24
21	III	20.4	5.1	6.5	0.7	0.3	. .	. .	692
22	IV	0	5.1	6.6	6.5	6.5	6.3	6.1	0
23	IV	3.1	5.1	6.4	6.3	5.2	4.4	3.7	0.2
24	IV	10.2	5.1	6.5	3.6	2.1	1.8	. .	34
25	IV	20.4	5.1	6.5	1.5	0.7	0.7	. .	733
26	I	0	5.1	6.9	2.4	2.3	2.2	2.0	0
27	I	3.1	5.1	6.7	2.2	1.6	1.4	1.3	0.2
28	I	3.1	5.1	7.0	2.0	1.6	1.4	1.2	0.2
29	I	10.2	5.1	6.8	1.4	0.2	0.1	. .	36

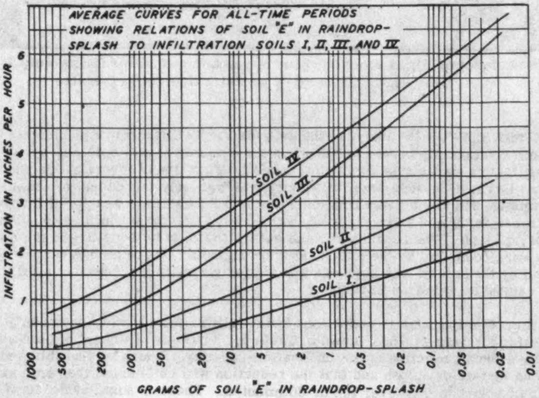

Fig. 6--Curves showing the relationship of splash of soil (E) to infiltration-capacity for four soils problem needs further study. Of course the extent of the reduction in infiltration-capacity caused by ten grams of soil-splash will vary between soil-types, and also between soil conditions within each type.

The ten grams of soil-splash previously referred to will cause the greatest reductions in the infiltration-capacity of any one type of soil when rates of infiltration are highest. The splash is least effective when rates of infiltration are lowest. Through the process of infiltration, the fines are washed into the surface pores where they decrease the infiltration-capacity of the soil. The amounts of fines so carried down into the surface pores will depend on (1) the concentration of fines in the surface-water (which is a function of the quantity of splash), and (2) rates of infiltration. Thus, to anticipate the effects of soil-splash on reducing an infiltration-capacity of the soil, one must know the infiltration-capacity at the beginning of the period under study.

Much more experimental study will be necessary before splash-data can be used to fullest advantage for studying infiltration rates and capacities. However, information at hand is sufficient to show that soil-splash caused by raindrop-impacts is harmful to the infiltration-capacity of a soil, and that a principal objective of the conservationist must be to prevent the dispersal of clods and aggregates and the splash of soils by raindrop-impacts. Splash-samplers that will show which conservation practices achieve this objective, and which fail to achieve it, should represent a worthy addition to the equipment of those studying the effectiveness of different cropping and tillage practices on conserving water.

ELLISON and SLATER [9] attributed the greater part of the differences between infiltration-capacities of these four soils to differences in their aggregation and clay-content. Those soils highest in percentages of small aggregates and clay were found to have the lowest infiltration-capacities. The percentages of aggregates less than 0.105 mm and the clay-content, respectively, are shown in the second and third columns of Table 6. Columns 4 and 5 show infiltration-capacities for each of the soils at two different levels of E.

Table 6--Comparison of physical properties and infiltration rates

Soil	Aggregates less than .105 mm	Clay	Infiltration for (E) = 0.1	Infiltration for (E) = 35
	pct	pct	iph	iph
I	56	14	1.7	0.2
II	33	12	2.8	0.7
III	20	12	5.2	1.4
IV	20	6	5.7	2.1

Surface-flow

Energy of surface-flow--The energy of surface-flow is a function of mass and velocity of the flowing water. The mass is determined by the quantity and quality of the flow, whereas the velocity for any given mass is affected principally by the length of the path of flow for each unit of vertical fall, and the resistance to flow in each unit of slope length. A reduction in either the mass or the velocity will reduce kinetic energy. Conservation programs are designed to accomplish reductions in the energy of flow through reducing either the mass or the velocity of flow, or both.

This discussion of flow-energy will be limited to flow which may be referred to as pre-channel, or sheet flow. There is no sharp distinction between pre-channel flow and channelized flow, but that which is referred to as pre-channel flow in this paper will usually occur on more than 90 per cent of the field-surface during storms. It transports soil in the sheet-erosion process and it may develop sufficient energy to cause some erosion. For these reasons the energy of pre-channel flow in all types of crops, on all ranges of slope and with all types of tillage practices, is of greatest importance to the soil conservationist.

Very few measurements have been made of velocities of pre-channel flow in open fields. About 200 such measurements were made at Coshocton, Ohio, in corn, wheat, and meadow, all on a number of different slopes. These were made in open fields. Figure 7 shows the equipment used. Water was applied over a weir, at uniform depth across the full width at the upper edge of the selected area. The determinations of velocities were made by injecting a potassium-permanganate solution into the flowing water and measuring the elapsed time required for the color-front to move through a section of known length. The velocity was then determined by dividing the distance by elapsed time.

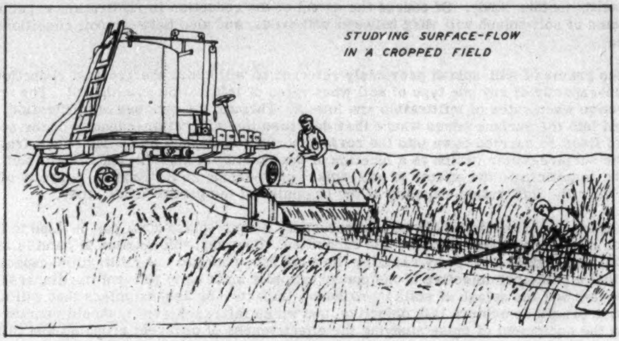

Fig. 7--Sketch showing equipment used for studying surface flow

The velocity obtained by this method is approximately the maximum velocity of translation, and the energy-calculations made from these measurements do not include energy of turbulence. However, for lack of better methods, these studies were continued, determining only the velocity of translation, in an effort to further the studies of flow energy in various cropped fields. There is such great variation between velocities of translation in the different crops that great refinement in experimental techniques, although desirable, are not necessary for obtaining some valuable flow-data which will be useful in evaluating some of the conservation aspects of different practices and in analyzing runoff hydrographs.

Analyses of the Coshocton data have not been completed but some representative values of $V^2/2g$ (the velocity-head) are shown in Figure 8 for 16 per cent slopes, having meadow, wheat on the contour, corn on the contour, and corn cultivated up and down the slope.

Values of MANNING'S n have been computed for the Coshocton experiments. Preliminary examination of these results leads one to conclude that although the MANNING formula may not be entirely accurate when applied to flowing water on a broad field surface, yet it may be used as a guide in estimating probable velocities to expect on different slopes having different crops and different tillage practices. Some of the principal factors affecting values of n are type, density, stage of growth, and evenness of distribution of vegetation, the presence of rills and gullies, and the quantities of water flowing. If the values of n could be obtained for a number of crops and tillage practices, then energy diagrams, such as shown in Figure 8, could be prepared for the full range of slopes encountered in field work.

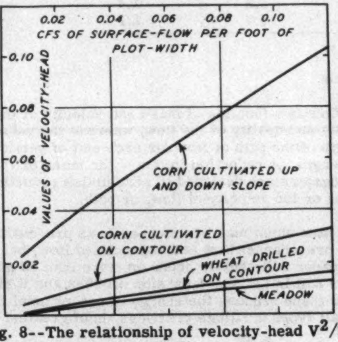

Fig. 8--The relationship of velocity-head $V^2/2g$ to various crops and tillage practices

Effects of velocity head on soil loss--An increase in the energy of surface-flow will increase its carrying capacity and generally it will cause an increase in rates of erosion. In these experiments the rates of erosion were increased with each increase in $V^2/2g$. Figure 9 shows soil loss in tons per acre per hour plotted against values of $V^2/2g$ for two of the experiments. Increases in soil-erosion which result from increases in velocity may vary greatly in different soils, and wide variations may be found within a given soil. One should not expect to find a fixed relationship between velocity-head and rates of erosion during the course of a single rainfall because conditions within the soil which affect its erodibility may undergo

change while the soil is being wetted. During storms these changes occur within a matter of minutes, while during the drying-period, between storms, considerable change takes place in a matter of days or even hours. Just as an emery wheel traveling at fixed speed will abrade different metals at different rates, so will a given amount of flow-energy erode soils of different erodibility at different rates. However, high energy of surface-flow may cause more or less damage to all soils, regardless of type of soil or of its condition. And, it may be assumed that any increase in velocity head will increase soil-erosion. Immediate and very practical use can be made of data which will show the energy of surface-flow that is associated with different crops and tillage practices on open fields.

Effects of surface-flow on infiltration--The only information available to the writer, which relates to the effects of surface-velocity on infiltration, were obtained in some of his experiments at Coshocton, Ohio. In this work the water was passed over a glass filter-cloth spread over a bed of washed sand. In a series of tests with velocities varying from 0 to about six feet per second, it was found that the velocity of surface-flow did not affect rates of infiltration.

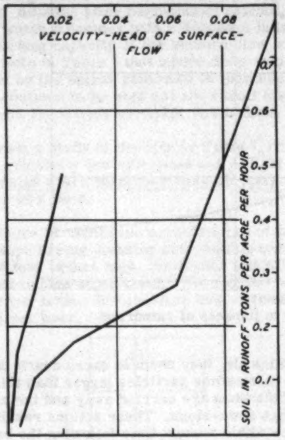

Fig. 9--The relationship of soil-loss to velocity-head

If flow over a soil-surface would cause a shifting of particles of soil, and these shifts changed the infiltration-capacity of the soil, then one would expect changes in rates of infiltration. However, where the surface-flow does not affect the porosity of the soil, velocities of 0 to about six feet per second have no appreciable effect on rates of infiltration.

Some effects of rainfall and surface-flow working together

Erosion which leads to a loss of soil from the surface of the land can be thought of as embracing two separate processes. In the first process, particles are separated and set in motion. In the second, they are transported indefinite distances. Outside the rills and gullies, on the more smooth surfaces of the field slopes, most of the particles of the soil are separated and set in motion by raindrop-impact, while the surface-flow, in addition to causing some erosion, helps to transport the eroded materials down slope.

Some experiments by IZZARD and AUGUSTINE [10] indicated that raindrops falling on shallow surface-flow may retard the translational velocities. However, experiments have shown that this retardation does not reduce the amount of soil transported by the flow. On the contrary, evidence points to a considerable increase in the soil carried by the surface-flow when it is exposed to raindrops.

Differences in characteristics of rainfall will have considerable effect on the soil carried by the runoff. The following is quoted from the report, "Studies of raindrop erosion," [5], "It was observed that raindrop impact, under certain conditions, would move stones as large as 10-mm diameter when they were partially or wholly submerged in water. When raindrops struck these submerged stones, they would rise and frequently they would move some distance down-slope. Where there was surface-flow, this would assist the downhill motion even though the surface-flow acting alone would not move them."

LAWS [1] reported that an increase in drop-size increased the erosion losses, which were measured in terms of concentration of soil in the runoff, by as much as 1,200 per cent. Results from the Coshocton work also show that the size and velocity of raindrops have a very pronounced effect on soil carried by the runoff. These results are shown in Figure 10. The plot used in these experiments was five feet long and six feet wide, and the surface was free of rill- and gully-erosion.

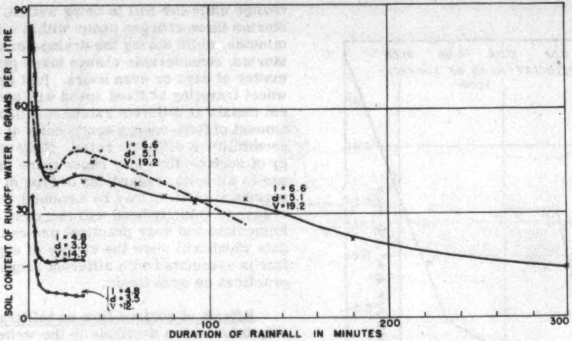

Fig. 10--The relationship of soil-loss to impacts of raindrops

When the raindrops loosen the soil and splash it into the air, they seem to carry nearly all of the particles of two mm or less in diameter. They also carry some particles larger than this. As these splashes fall back into the surface-water, many of the fines are carried away and the coarse particles may settle out after being moved a short distance down-slope. These actions result in an accumulation of excessive coarse material on the surface within a short time following the beginning of rainfall.

Results shown in Table 7 indicate that even during the first two minutes of rain, the splashed material is higher in sand and fine gravel than is the original soil. They also show that from six

Table 7--Aggregate analyses of original soil material (eroded Muskingum silt loam) of the splashed material for various intervals of time from the beginning of the rainfall, and of the material in the runoff; raindrop size, 5.1 mm

Raindrop velocity	Time interval	Sand and gravel, size of grain, mm						Silt and clay
		1 - 2	0.5-1	0.5-0.25	0.125-0.25	0.05-0.125	0.05 - 2	<0.05
fps	min	pct	pct	pct	pct	pct	pct	pct
Original material		0.55	1.81	2.27	3.49	17.16	25.28	74.72
Material in raindrop splash								
19.2	0-2	2.11	2.51	2.82	3.87	16.09	27.40	72.60
19.2	6-8	5.01	2.76	2.97	3.76	18.08	32.58	67.42
19.2	13-15	4.36	2.47	2.92	3.90	17.68	31.33	68.67
		Average, 19.2 fps velocity					30.44	69.56
18	0-2	1.91	2.65	2.75	3.89	16.36	27.56	72.44
18	6-8	2.79	2.63	3.22	4.75	17.76	31.15	68.85
18	13-15	1.43	2.46	3.42	4.77	19.69	31.77	68.23
		Average, 18 fps velocity					30.16	69.84
15	0-2	1.20	2.83	3.28	4.27	16.46	28.04	71.96
15	6-8	2.63	3.49	3.69	4.50	19.55	33.86	66.14
15	13-15	1.79	2.30	3.13	4.03	18.03	29.28	70.72
		Average, 15 fps velocity					30.39	69.61
12	0-2	1.01	2.22	2.87	4.19	16.14	26.43	73.57
12	6-8	2.29	3.06	3.69	4.22	17.68	30.94	69.06
12	13-15	2.44	3.62	3.79	4.37	17.33	31.55	68.45
		Average, 12 fps velocity					29.64	70.36
Material in runoff		0.25	0.36	0.49	0.67	3.20	4.97	95.03

to eight minutes after beginning of rainfall, the concentration of coarse material is even greater than during the first two minutes. The apparent decrease in coarse material during the period of 13 to 15 minutes after beginning of rainfall, shown in Table 7, may be caused by an increase in runoff which coincides with a decrease in infiltration. This increase in runoff would increase the transporting capacity of the surface-flow so that it would carry away more of the large size particles. Note in Table 7 that where drop-velocity was only 12 feet per second, the coarse material carried by the splash continued to increase throughout the 15-minute period. Here the infiltration would continue to be high and the runoff low for a longer period of time, and the low runoff may not transport the coarse particles down-slope.

From a study of the data in Table 7, one may conclude that storms of small drop-size, which fall at relatively low velocities and of light intensity, intense rains of very short durations, or intense rains which terminate very abruptly would tend to leave an excess of coarse particles on the surface of a field.

Figure 11 shows the concentration of soil in the runoff from a plot 20 feet long on a ten per cent slope having standing oats stubble and spring seeding of clover and timothy which was approximately four inches high. Artificial rainfall and surface-flow were applied alternately and in combination in this experiment. The rainfall was applied with a Type-F simulator at a rate of 3.3 inches per hour. Surface-flow was applied with the equipment shown in Figure 7, at a rate of 20 inches per hour.

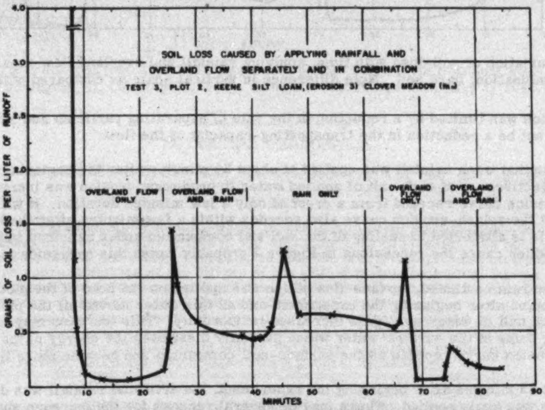

Fig. 11--Variation of soil-loss with time, applying rainfall and overland flow separately and in combination, clover meadow

Figure 12 shows the concentration of soil in the runoff from a bare plot. Here the rainfall and surface-flow were applied at the same rates used on the plot represented in Figure 11, and it will be noted that the soil content of the runoff is approximately 40 times as great as that in the runoff from the plot which had the stubble and young meadow-grass cover.

Most of the erosion which occurred on these plots can be classed as sheet-erosion. It was previously stated that water applied as raindrops was more effective in separating soil-particles and setting them in motion than was surface-flow, and that the principal function of surface-flow in pre-channel stages was to transport the eroded particles. The results in Figures 11 and 12 offer a splendid opportunity for studying the relative effects of raindrops and surface-flow in accelerating the sheet-erosion process.

Referring to Figure 11, it will be noted that the first flow passing over the surface of the plot removed considerable soil for a very short period of time. This loss probably consisted of the loose particles and flakes on the surface, and those particles released through slacking. The erosion-curve receded from its crest to approach zero in about two minutes time. During this recession in the erosion-curve the flow remained constant, and therefore it can be assumed that the

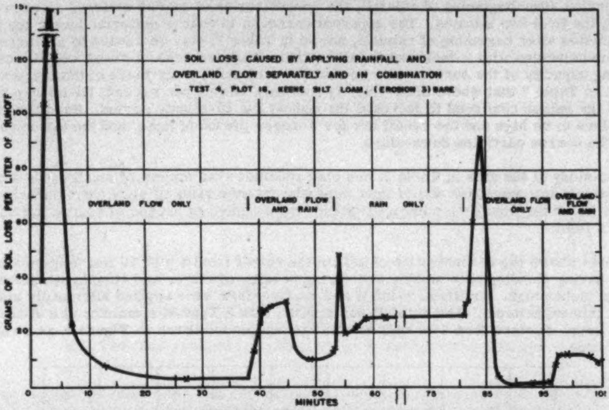

Fig. 12--Variation of soil-loss with time, applying rainfall and overland flow separately and in combination, bare soil. Note difference in vertical scale as compared with Fig. 11

rate of erosion was limited by a reduction in the rate of separating particles and setting them in motion, and not be a reduction in the transporting-capacity of the flow.

Note also that when rainfall was applied at about 24 minutes after the beginning of the experiment, the effectiveness of each unit of applied water in producing erosion was increased. But here again the erosion curve receded from a crest of only a few minutes duration. It will be seen on Figure 2 that the splash-erosion curve also recedes within a few minutes after the beginning of rainfall. This is attributed to sealing of the soil and compaction under raindrop impacts. The same phenomena which cause the recessions in Figure 2 probably cause this recession in Figure 11.

While the rain continued, surface-flow which was applied on the head of the plot was discontinued about 39 minutes after beginning the experiment and as this water moved off the plot, erosion produced by each unit of water was again increased temporarily. This increase may have been caused by removing some of the surface-water which partially dissipated the energy of the raindrops. But again the erosion curve receded as the surface-soil compacted and became more firm.

At about 63 minutes after beginning the experiment, the artificial rainfall was discontinued and surface-flow was again applied. There may be several reasons for the increase shown by the erosion curve at this point. One would be that following the rainfall, which ceased instantaneously, there would be some loose particles left on the surface. Another, that some of the particles carried by the splash were deposited on stems of plants and piled around their crowns. The surface-flow would remove many of these. Where there is very little surface-flow, one usually finds soil columns resembling those shown in Figure 3. These are usually capped by stones, stems, and leaves. Surface-flow of 20 inches per hour may remove many of these columns and this type of erosion would cause the erosion curve to rise.

When raindrops were applied along with the surface-flow about 74 minutes after the beginning of the experiment, the erosion again increased, but not to the magnitude attained previously by applying rainfall and surface-flow simultaneously. The principal conditions which limited the rise shown by the erosion-curve at this time were developed by surface-compaction.

The curve in Figure 12 is similar to that in Figure 11, the principal difference being that this curve represents a bare soil and the quantities of erosion were about 40 times as great as those for the young meadow plot shown in Figure 11.

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Soil Conservation Service,
Washington 25, D. C.

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NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 430, 440, 444, 455, 456, 458, 459, 460, and 462)

NOTES

Conference on relationship of ground-water levels to minimum stream-flow--A conference on the relationship of ground-water levels to the minimum flow in streams was held in the offices of the Pennsylvania Water and Power Company at Safe Harbor, Pennsylvania, on October 17. In attendance were representatives of six offices of the United States Geological Survey; the office of the United States Weather Bureau at Harrisburg, Pennsylvania; the Baltimore office of the United States Corps of Engineers; the United States Soil Conservation Service; the Susquehanna Power Company; and the Pennsylvania Water and Power Company. Carroll F. Merriam made a presentation of the studies he has made and methods he has devised in connection with this matter, and J. V. Stumpf, also of the Pennsylvania Water and Power Company, explained the actual use that is made of the findings, following which there was a general discussion.

Water conservation in Ohio--By Act of June 20, 1945, the Ohio legislature created the Ohio Water Resources Board to collect, study, and interpret all available information and statistics pertaining to the supply, use, and conservation of underground and surface water in the State. The Board has authority to prescribe rules for the construction, operation, or abandonment of wells, and to pass upon projects for the use of surface waters. C. V. Youngquist, formerly District Engineer of the United States Geological Survey in Ohio, has been appointed Chief Engineer.

Ground-water study in Colorado--The Colorado State Water Conservation Board has plans for a six-year comprehensive study of ground-water for development of additional supplies for irrigation, stock water, and municipal use. S. K. Lohman, of the United States Geological Survey, has been placed in charge of this cooperative program, with headquarters at Denver.

Organization of the Washington group--Members of the Union affiliated with the Section of Hydrology met at a luncheon meeting on November 29 to talk over needs and plans for the organization of the Washington members. Franklin F. Snyder of the Office of the Chief of Engineers of the War Department spoke concerning his experiences in making forecasts for the Rhine River in connection with military operations last winter and spring.

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 440, 444, 455, 456, 458, 459, 460, and 462)

NOTES

Notes on Parícutin Volcano--During the six months since June, 1945, both flow and explosive activity have continued at Parícutin. Lava has been issuing continuously from one to four bocas at the foot of the southwest slope of the cone, and for the greater part has flowed toward the buried village of Parícutin, although one stream flowed around the south and west side, between the main cone and the parasitic crater Zapicho. Lava has now been built up around the foot of the cone to a depth of several hundred feet. John M. Barb reported that on the night of October 28 a new vent opened about halfway up on the northwest side of the volcano, and lava was pouring down the side of the cone when Mr. Barb left. An outstanding cannonade which lasted about 20 minutes and threw bombs higher than usual preceded the inception of the new flow; steam, what appeared to be flame, and a considerable amount of light were emitted from the new vent. K. B. Krauskopf reported that for several days early in November great quantities of hot rocks were blown out, and two active lava streams are developing into major lava flows. Explosive activity during the past few months has consisted mainly of the continuous emission of steam and the ejection of bombs; little ash has been ejected.

For ten days in July, several scientists and others were at the volcano to participate in helicopter flights made under the auspices of the United States Army. Among the party were G. D. Colchagoff of the United States Army Air Forces; Ivor T. Sikorsky, inventor of the helicopter; L. C. Graton of Harvard University; O. H. Gish of the Department of Terrestrial Magnetism, Carnegie Institution of Washington; W. F. Foshag of the United States National Museum; F. W. Bullard of the University of Texas; E. T. Nichols, Jr., of Tucson, Arizona; Frederick H. Pough of the American Museum of Natural History; D. J. Cederstrom of the United States Geological Survey; W. A. Eggler of Alma College, Michigan; Arnold P. Elliott of the United States Weather Bureau; Ezequiel Ordoñez, Manuel Medina, and Paul Waitz of Mexico.

Konrad D. Krauskopf started work at the volcano early in November. He will be stationed there for about four months to carry on studies for the United States Geological Survey with funds provided by the Inter-Departmental Committee for Cooperation with the American Republics, under the auspices of the Department of State.

A mosaic of the area around the volcano has been compiled by the Compañia Mexicana Aerofóta from aerial photographs taken in April, 1945, for the Committee for the Study of the Parícutin Volcano. Prints can be purchased from the Company in Mexico City. The prices are 225 pesos for the full-scale aerial mosaic at 1:10,000; 100 pesos for copies on scale 1:20,000; and 50 pesos for copies on scale 1:40,000.

Committee on Parícutin Volcano--The sixth meeting of the United States Committee for the study of Parícutin Volcano was held in Washington on October 19, 1945. In reviewing the work undertaken during the past few months, a recommendation was made to request an appropriation of $1000 for the purpose of preparing a complete photographic file of the volcano's history. The repository is yet to be selected. Among other interesting items presented were the report on atmospheric electric work presented by O. H. Gish, and the report on erosion presented by W. C. Lowdermilk. Dr. Lowdermilk stated that about 30 per cent of the ash deposit has already been removed by the process of erosion.

Reported activity at Crater Lake--In the November 2 issue of Time Magazine, it was reported that during the previous eight weeks four large gas or dust bubbles had issued from Crater Lake. As of the middle of November no official confirmation of the activity had been received in Washington.

Corrigenda--The following corrections are noted in the Transactions:

Volume 25, Part VI, 1944, p. 964, Paper by C. F. Izzard on "The surface profile of overland flow," the titles of Figures 5 and 6 are interchanged. Figure 5 should have the title, Product λR as a function of rainfall-intensity for the three types of surface tested. Figure 6 should have the title, Resistance-coefficient as a function of Reynolds number for steady uniform flow on paved surface: Series II.

Volume 26, Number II, October, 1945, p. 265, in the item relating to Arctic Institute of North America, Albert Lincoln Washburn (not A. T. Washburn) has been appointed Director of the Institute.

Transactions, American Geophysical Union Volume 26, Number III December 1945

SURFACE-RUNOFF AND INFILTRATION

Hans Albert Einstein

The terms, "surface runoff" and "infiltration," which form the title of this paper, are usually associated with a piece of land and the precipitation falling upon it. They suggest that this ground is porous, that part of the water will infiltrate into it while the rest runs off along the surface or evaporates. The ratio according to which the precipitation is divided into surface and subsurface water is of primary importance to plants, since only the subsurface water is available to them, whereas the surface runoff is often detrimental, because it erodes the very topsoil in which they grow. Furthermore, the surface runoff supplies the engineer with most of his problems of flood-control and water-utilization; whereas, infiltration-water is effectively eliminated from such problems as long as it stays underground or is evaporated or transpired. For these reasons, agriculture is constantly endeavoring to increase the percentage of infiltration, and a continuous program of research aims to find agricultural practices which favor infiltration and reduce surface runoff. In dry areas this increased infiltration often may mean the difference between success and failure of a crop.

In humid regions where the water-supply is ample, the increase of infiltration-rates is desirable as an erosion-control measure. In dry regions, however, where agriculture must be based on intensive water-utilization, even the highest infiltration-rates obtainable in the watershed cannot prevent the surface runoff of a part of the available water-supply and it has become increasingly important to learn under what conditions infiltration of the remaining surface runoff-water can be achieved farther downstream. The use of spreading grounds for recharging groundwater-basins is the engineer's answer to this problem. But nature has also provided for natural spreading grounds in the alluvial plains and cones, and it is the object of this paper to describe in a general way how those natural spreading grounds work and to suggest that they be systematically studied.

In studying the performance of both natural and artificial spreading-grounds, it is of first importance to compare their area with that of the total watershed. Usually, the spreading-grounds are only a small percentage of the total watershed and they can, therefore, be effective only if they have infiltration-coefficients which are many times larger than the average values in the watershed.

Surface runoff, because of its ability to scour, tends to concentrate its flow into channels. This concentration, in turn, increases both the velocities and the scouring ability of the flow. The resulting vicious circle finally reaches a state of semi-equilibrium governed either by the resistance of the material which is being eroded or by the amount of sediment which is moving along the stream-bed, and currently replaces the bed-particles as soon as they are eroded.

What are the infiltration-rates in such semi-stabilized stream-channels? This is the main question governing the significance of infiltration from natural streams. Infiltration in general increases with the increasing pressure-gradient and with both the total volume and the size of the pores in the soil-material. From this it is readily understandable that infiltration is usually insignificant in channels where equilibrium is achieved by high resistance of the soil-material. A soil or rock that is dense is resistant to scouring usually because it affords few opportunities for either water or moving sediment to attack it and bring about its disintegration. But in a dense material the total amount and the size of pores is small and, consequently, a relatively low infiltration-rate may be expected. The only exceptions are certain calcareous rocks which develop caves and big underground channels, which enable large quantities of water to move underground owing to the great size of the single channel rather than to the total pore-volume. The water moves in those underground channels as rapidly as in surface channels and might well be classified as surface flow.

It will be sufficient, therefore, to study infiltration in the streams which are stabilized by sediment-movement, the so-called alluvial or graded streams. An alluvial stream is characterized by the deposit over which it flows. Deposited by the stream itself or perhaps by a different stream which was flowing through the same region in former times, this alluvium fills an old valley or depression, adjusting the general profile of the present stream to its conditions of flow and sediment.

Although the thickness of the alluvium may vary from only a few feet to several hundred and form a deposit varying in width from the width of channel to that of a wide valley, it is always composed of loose sediment-particles. Such deposits contain from ten to 40 per cent voids or pores of rather large size which can be filled with water by infiltration and drained again by natural or artificial means.

Infiltration from an alluvial stream-channel into the underlying alluvium is governed by the same factors as infiltration in general, namely, the pressure-gradient, the total volume of the pores and their size. The pressure-gradient depends mostly upon the position of the groundwater-level in relation to the water-surface in the stream-channel. The total pore-volume depends mostly upon the size-composition and texture of the alluvium. A well-sorted material has more pore-volume than a mixture of all sizes, and the better all the small particles are packed into the interstices of the larger ones, the smaller is the total pore-volume. The size of the single pores is proportional to the grain-size, and, therefore, rather large in most alluvial deposits.

For the evaluation of infiltration-data, the resistance against inflow of water may be divided into two parts: First, there is a surface resistance; and second, there is the normal resistance in the alluvium. The surface effect is known to play an important part in infiltration. A surface layer may be compacted by the impact of the raindrops and by other atmospheric influences. Fine silt- and clay-particles fill the small pores of a layer immediately below the surface, while particles like coarse sand and pebbles remain at the very surface, protecting the layer underneath. This effect causes a special resistance which often is much higher than the normal resistance of the soil underneath.

In the stream-bed a somewhat similar development takes place when the rates of sediment-transport are small. At falling stages the flowing water is less and less able to keep the larger particles moving. Those particles are deposited in the bed-surface in a typical shingle-pattern, with their flat sides up and tilted down somewhat on the upstream side. In this position they are most stable against attack by the water and most effectively cover the bed. The water still circulates slowly around the individual particles, but moves so slowly between the particles that it drops all the fine sediment-load there, effectively closing the pores of the bed. This phenomenon was very distinctly observed by the writer in bed-load experiments conducted in a flume 150 feet long, with six-by-six-foot cross-sections. In those experiments such quantities of silt were continuously ground off the moving bed-particles, that a refill of clean water invariably lost its transparency after a few minutes of flow. On the other hand, if muddy water was circulated at a speed at which the rate of sediment-transportation was very small, it cleared up by itself and the silt was found afterwards in the pores of the upper bed-layers. This same effect could not develop at higher rates of transport because then the very layers in which the silt had been deposited, periodically were being eroded and redeposited. Thus, the fine particles are thrown back regularly into suspension after deposition in the bed. It would seem probable, therefore, that infiltration in the bed of an alluvial stream is less hampered by surface effects when strong bed-load movement occurs.

Very few data on infiltration-rates in stream-beds are available and those that do exist are not very satisfactory. Values of one to five inches per hour are mentioned, and these are definitely much larger than those for most soils in the same watersheds. In discussing and applying such figures, it is important to remember that the rates of infiltration depend upon both the soil-material through which the water percolates and the pressure-distribution causing the percolation. Since the pressure-distribution in a river-bed changes greatly with the position of the groundwater-level, two extreme types will be considered.

The first type is characteristic of a humid climate whose streams flow continuously. The stream slopes are usually below 0.003 for watersheds over two or three square miles. In the alluvial deposits along those streams the water-table is about level with the surface of the stream The slopes of the water-table in the direction of and across the valley are of the same order of magnitude as the slope of the open water-surface. Unless heavy influx of water from the sides increases the drop towards the stream-channel, the velocities of the groundwater are very low in all directions. During floods, however, when the stage in the surface-channel changes rapidly, the groundwater-surface tends to follow that change, causing strong groundwater-movement from the channel into the basin during rising stages and back to the channel during falling stages. This movement causes a retention of flood-waters in the groundwater-basins, lowering the flood-peaks and prolonging the duration of the receding stages of the flood. This is a distinctly desirable feature, the extent of which depends largely upon the size of the groundwater-basins and upon the permeability of the sediment they contain.

Another typical consequence of the exchange of water from the stream to the basin and back during floods is the sliding of channel-banks, which is especially pronounced in pervious bank material. Bank-erosion in such streams is not a continuous action, but occurs by "caving in" of smaller or larger complexes of bank material, especially at flood-time. At rising flood-stages, water percolates into the bank, saturating the soil and raising the groundwater-level. Under these conditions the water-pressure in the open flow is higher than in the groundwater and this difference in pressure results in a force towards the banks which stabilizes the banks and, therefore, caving seldom is observed during rising stages. As soon as the peak has passed, the difference in pressure is reversed as the groundwater-level slowly follows the stream-level back down and water begins to percolate towards the channel. During this same period, the stability of the bank-material is the lowest since the material is saturated. Both of these factors tend to cause bank-caving, and, as confirmed by field-observations, most bank-caving occurs during falling stages of the flood.

The second extreme river-type is the dry-climate mountain stream. Small total annual precipitation, combined with high rates of sediment-production result in deep alluvial deposits, steep channel-slopes, and low groundwater-levels. With their headwaters in the mountains, these streams are usually fed by the torrential rains of a semi-arid country which results in flood-discharges comparable with those encountered in similar watersheds with humid climate. The resulting concentrations of sediment approach those of mud-flows during flood-stage. Such streams often have slopes much steeper than 0.01 and are usually intermittent. Often the surface flow will cease a few hours after the flood-peak, but in some cases, it will persist for a number of days, depending upon the size of the watershed and the character of the flood.

These streams can be understood only as alluvial streams, that is, as high-intensity bed-load carriers. Like all alluvial streams, they usually seem to have a rather regular profile, indicating that the profile, together with the slope, has some fundamental significance for the flow. This fact can be explained rather easily as follows: If water flows through a lined channel of sufficiently large cross-section, any discharge can be conducted through this channel at any slope. It is true that the velocity of the water will be high on steep slopes and low on flat slopes, that the same discharge will fill the channel to a greater depth on a flat slope and to a lesser depth on a steep slope, but still, any discharge will flow at any slope. In an alluvial stream, the same conditions prevail concerning the water. But here another condition enters the problem, namely, that one and only one amount of bed-load can be transported by a single discharge at a given slope. This means that the stream not only drops sediment surpassing its capacity, but also brings the load up to capacity by scour from the bed if insufficient amounts of sediment are supplied from the watershed. If this scour or deposition persists, it will gradually change the profile of the stream until its sediment-capacity equals the sediment-output of the watershed.

No attempt is made here to describe in detail our knowledge about this delicate equilibrium between sediment-output of the watershed and the carrying capacity of the stream as expressed by the laws of transportation, nor will any formulas be cited, as it is fully sufficient at the moment to know that laws do exist governing the rates of transport which can be expressed in formulas, and that, in general, the ability to transport in any reach of a stream will increase with the slope. Many other variables of the stream, such as channel-width, bank-height, and bank-roughness, have a distinct effect on the capacity, but usually are not changing very much under natural conditions. However, there is one question that needs to be clarified before the main question of infiltration can be taken up. It has been found that for a given flow, sediment-particles from a certain maximum grain on down to the finest are moved simultaneously. How do different grain-sizes count in making up the capacity of the stream? What happens when certain grain-sizes are suddenly missing? Can they be replaced by others and how? In answering these questions, it is most helpful to define the capacity of a stream as the rate at which particles must move in the stream to replace bed particles at the same rates as the flow removes them from the bed. This definition automatically reduces the range of grain-sizes which must be included in the capacity of a stream to those which are found in the stream-bed. So much about the alluvial mountain stream in equilibrium. Wherever this equilibrium is disturbed by man, either by the change of runoff or sediment-supply in the watershed, or by encroachment into the stream-channel below, the stream must be expected to react with the above described scour or deposit. It will develop a new equilibrium-condition whereby the changes are especially violent in streams with high sediment-loads.

Coming back to the infiltration-problem of the dry-climate mountain stream, the rules of infiltration must be combined here with those of stream-equilibrium. It is almost impossible to give a general solution of this combined problem in which each part is in itself difficult to handle. However, if the discussion is confined to a typical example, the important features of the problem become clear. Let us assume that a mountain stream carrying a high sediment-load enters a wide basin through a gorge cut into rock. In the gorge the entire flow is concentrated in a narrow surface-channel, the slope of which is ample to prevent deposition of sediment. It may be assumed that the watershed above this point includes some porous, groundwater-bearing deposits which are able to store water for considerable time and to release it again to the stream as low-water flow. The hydrograph in the gorge will, therefore, include both flash-floods and long-duration low-water flows. Because of the steep slopes, sediment is moving at all stages, smaller amounts of finer sizes at low flows, larger amounts of all sizes at flood-flows. Outside the gorge the stream flows over pervious alluvial material. The groundwater, if there is any, has its level far below the bed. Water debouched through the gorge will immediately begin to infiltrate. The loss of discharge causes a reduction of the bed-load capacity and part of the bed-load is deposited in the channel. The water percolating through this material will filter out some finer particles, solidifying the new deposit. Gradually, the channel is filled and the flow begins to move sideways always choosing the lowest spots and gradually building a cone. The next flood may destroy part of the cone by cutting a channel through the new deposits, but at a greater or smaller distance from the gorge it also will lose its power. The receding discharges will fill the new channel again and soon the original cone will be restored and the only reminder of the flood is the deposit at the outer rim of the cone.

The cone is nature's solution of flood-disposal in semi-arid and arid countries. The drier the climate, the higher seem to be the sediment-concentrations and the steeper the cones. The analogue for the stream in the humid climate is the alluvial plane, which is a cone with flat slopes. Both the cones of debris and the alluvial planes have been a battle-field between the rivers and the natural vegetation. The river invites vegetal growth on these cones by supplying the necessary moisture, but continuously menaces it with destruction by floods. The mere presence of vegetation, on the other hand, tends to stabilize existing stream-channels on the cone, thus increasing the existing flood-hazard and preventing the necessary spreading of the flood-flows. The presence of a natural growth and of rather fertile soil often attracted agriculture, and when abnormally large floods occurred, they were considered as unforseeable catastrophes. To protect fields and buildings dikes were often built, and the flow was confined in a channel. But only very few of those channels were successful. Many kept filling and the streams continuously broke out of the assigned channels. Others began to cut deep gullies into the cones, draining them rather than providing for the necessary water-supply.

Where larger values were involved, more radical methods were tried, but even the most elaborate and expensive solutions, such as the combination of debris-basins at the mouth of the canyon with a lined channel down to the plains, are not necessarily satisfactory. Besides the high cost of installation, they involve a large maintenance cost for removal of debris from the basins. But, the greatest disadvantage of this solution is the fact that all infiltration on the cone is prevented by the lining of the channels.

If one remembers that the two types of streams are only the extremes of a continuous series of conditions, and if one remembers, furthermore, that different geologic and morphologic conditions in the watershed will create widely varying conditions of flow and sediment, it becomes evident that a systematic study of conditions of infiltration and runoff conditions in alluvial streams must be restricted to the fundamentals. Each application to a particular case has to be a separate study in itself in the course of which the conditions of flow and sediment of the watershed, as well as the drainage and water-requirements, must be considered when a plan is laid out to protect property on alluvial cones.

All over the world engineers have been baffled by streams which combine the problems of sediment-movement and infiltration, but only a few cases have been solved permanently. One of the most powerful tools, and one which is recognized increasingly as such, is the reduction of the output of water and sediment of the watershed by work in the watershed itself. By the establishment and maintenance of a permanent vegetal cover supported by structures stabilizing all the smaller and larger channels or by the construction of larger dams, it should be possible to establish stable down-stream channels without the use of the entire existing cones as settling- and infiltration-areas. However, much more research will be necessary before the engineer is able to predict the effectiveness of all these measures and to design satisfactory alluvial channels in areas where maximum infiltration-rates are desired.

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(Presented at Los Angeles Regional Meeting, February 27, 1945; manuscript received May 18, 1945; open for discussion until May 1, 1946.)

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GEODETIC WORK OF MEXICO DURING THE PERIOD FROM JUNE 1944 TO APRIL 1945

Manuel Medina

(Translated by F. W. Darling, United States Coast and Geodetic Survey)

Geodetic triangulation

The schemes of triangulation under development by observation or planned during the period of this report were the following:

(a) The triangulation along a part of the 104th meridian, west of Greenwich.
(b) The triangulation of the State of Guerrero.
(c) The extension of the triangulation of Lerma toward Parícutin.
(d) The continuation of the triangulation of the 26th parallel of latitude.

(a) The geodetic triangulation along a part of the 104th meridian west of Greenwich (see Fig. 1) originates in a side of the triangulation scheme of Jalisco and extends partly through that State and those of Zacatecas and Durango until it is connected with the triangulation of the 26th parallel of latitude. Its approximate linear extension is about 500 kilometers and it is composed of 9 geodetic figures in which the mean length of the sides is about 50 kilometers.

The measurement of angles at 12 stations of this triangulation scheme has been completed, with the use of a WILD theodolite with which the angles may be estimated on both circles to the nearest 0''.2, and by observing each direction 12 times in the two positions of the instrument. This triangulation covers an interesting zone, in which there are some aerial photogrammetric surveys that require control points, as well as some problems concerning state boundaries.

(b) The triangulation of the State of Guerrero (see Fig. 2) is a prolongation toward the south of the triangulation of the State of Morelos and extends through a region that had not been surveyed before. The reconnaissance of figures, with the necessary verification of the lines of sight and the computation of the strength of figure, has been practically completed, while the measurement of angles was begun in recent weeks.

(c) The triangulation in the Parícutin region (see Fig. 3) has been controlled by the immediate necessity of furnishing geodetic control points for the topographic and photogrammetric surveys of that region. It is composed of a pentagon with a central point and a quadrilateral with diagonals, both figures being tied into the triangulation of the Lerma River which has already been computed. Some of the stations of this triangulation, such as the ones situated on the ancient volcano Tancítaro and on the peak of Paracho, are more than 3000 meters above sea level, which has made difficult their observation on account of the persistence of the clouds and on account of being almost in a direct line with Parícutin Volcano, whose ashes and fumaroles obstruct the lines of sight.

(d) The measurement of angles on the arc of the 26th parallel (see Fig. 4) has been continued, the junction with the sections in La Laguna and Tamaulipas having been completed. At present the observations are made to the west of La Laguna, with the purpose of linking this triangulation soon with that of the State of Sinaloa.

Points of topographic triangulation

K. E. SEGERSTROM, Topographer of the United States Geological Survey, made the topographic survey of numerous points on the outskirts of Parícutin Volcano, whose positions were computed in this office and are being used as control points for the preparation of the topographic map of that region. These positions will soon be tied into the geodetic triangulation which is being accomplished now, so that the computation of their coordinates may be possible.

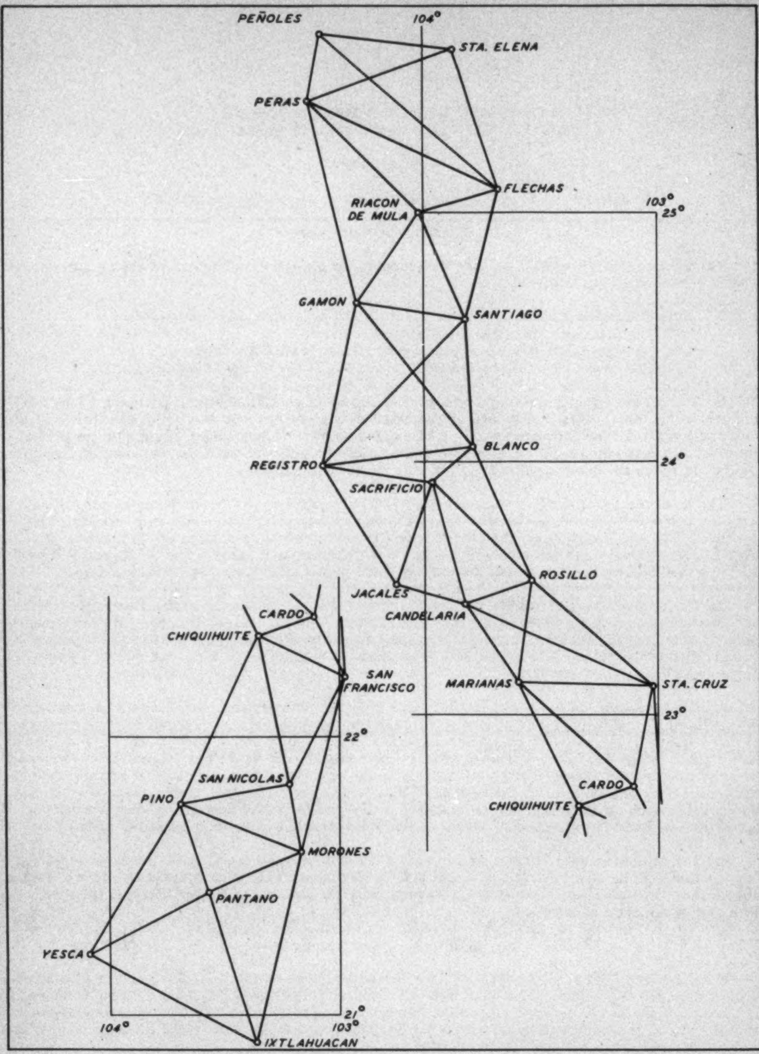

PEÑOLES
104°
STA. ELENA
PERAS
FLECHAS
RIACON DE MULA
103°
25°
GAMON
SANTIAGO
BLANCO
REGISTRO
24°
SACRIFICIO
ROSILLO
JACALES
CANDELARIA
CARDO
CHIQUIHUITE
SAN FRANCISCO
MARIANAS
STA. CRUZ
23°
22°
CARDO
CHIQUIHUITE
SAN NICOLAS
PINO
MORONES
PANTANO
YESCA
21°
104°
103°
IXTLAHUACAN

Fig. 1--Sketch showing primary triangulation along the 104th meridian

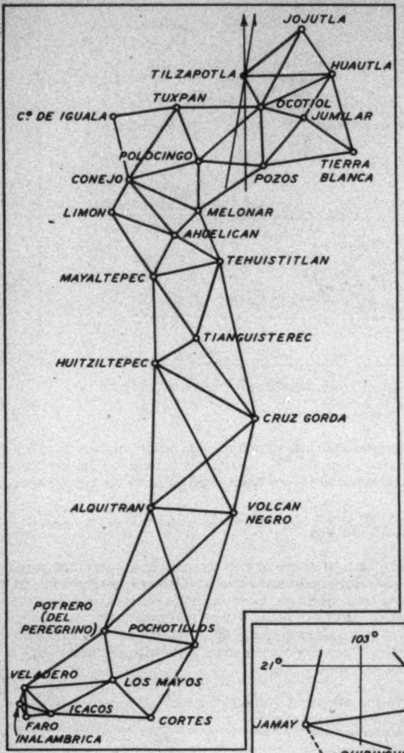

JOJUTLA
HUAUTLA
TILZAPOTLA
TUXPAN
OCOTIOL
JUMILAR
Cº DE IGUALA
POLOCINGO
TIERRA BLANCA
POZOS
CONEJO
LIMON
MELONAR
AHUELICAN
TEHUISTITLAN
MAYALTEPEC
TIANGUISTEREC
HUITZILTEPEC
CRUZ GORDA
ALQUITRAN
VOLCAN NEGRO
POTRERO (DEL PEREGRINO)
POCHOTILLOS
VELADERO
LOS MAYOS
ICACOS
CORTES
FARO INALAMBRICA

Fig. 2--Sketch showing the progress of the geodetic work in the State of Guerrero

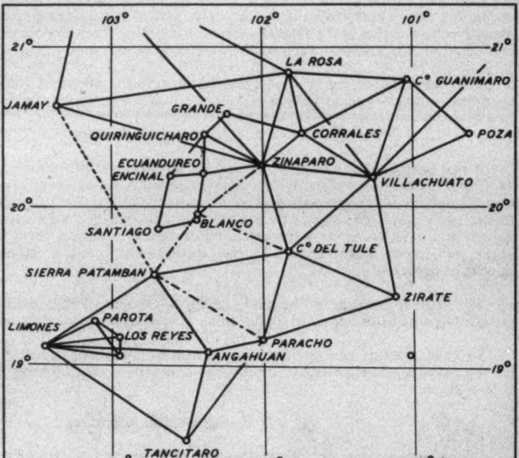

103°
102°
101°
21°
21°
LA ROSA
Cº GUANIMARO
JAMAY
GRANDE
QUIRINGUICHARO
CORRALES
POZA
ECUANDUREO
ZINAPARO
ENCINAL
VILLACHUATO
20°
20°
SANTIAGO
BLANCO
Cº DEL TULE
SIERRA PATAMBAN
ZIRATE
PAROTA
LIMONES
LOS REYES
PARACHO
ANGAHUAN
19°
19°
TANCITARO
103°
102°
101°

Fig. 3--Triangulation in the vicinity of Parícutin, State of Michoacán, linked with the Lerma-Santiago geodetic triangulation

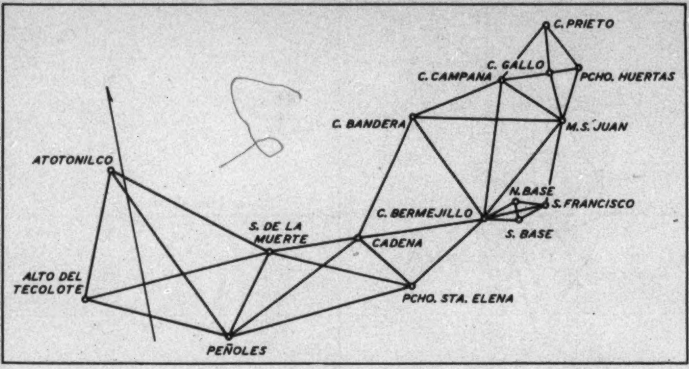


Fig. 4--Reconnaissance and triangulation along the 26th parallel of latitude

On the invitation of the United States Hydrographic Office, a topographic triangulation project has been begun along the coast of the Gulf of Mexico (see Fig. 5), to support a neighboring hydrographic survey in the Gulf. Some existing reconnaissances have been used to plan the topographic triangulation which figures in the next square.

Astronomy of position

For the purpose of establishing a LAPLACE status at some of the stations of the triangulation of Michoacán, an astronomical station of first order was determined in Los Reyes, Michoacán, at a point near the geodetic station "Limones." The astronomical instrument (zenith-meridian Repsold 2) could not be set up on that eminence on account of the difficulty of transportation and of installation. The observation of meridian transit of stars during four nights, the reception of radio signals of the United States Naval Observatory (NSS), and the observation of zenith distances of stars by the HORREBOW-TALCOTT method were accomplished.

In order to refer the astronomical position to the geodetic a small triangulation network was observed in which a base 1199.458 meters in length was measured.

Precise leveling

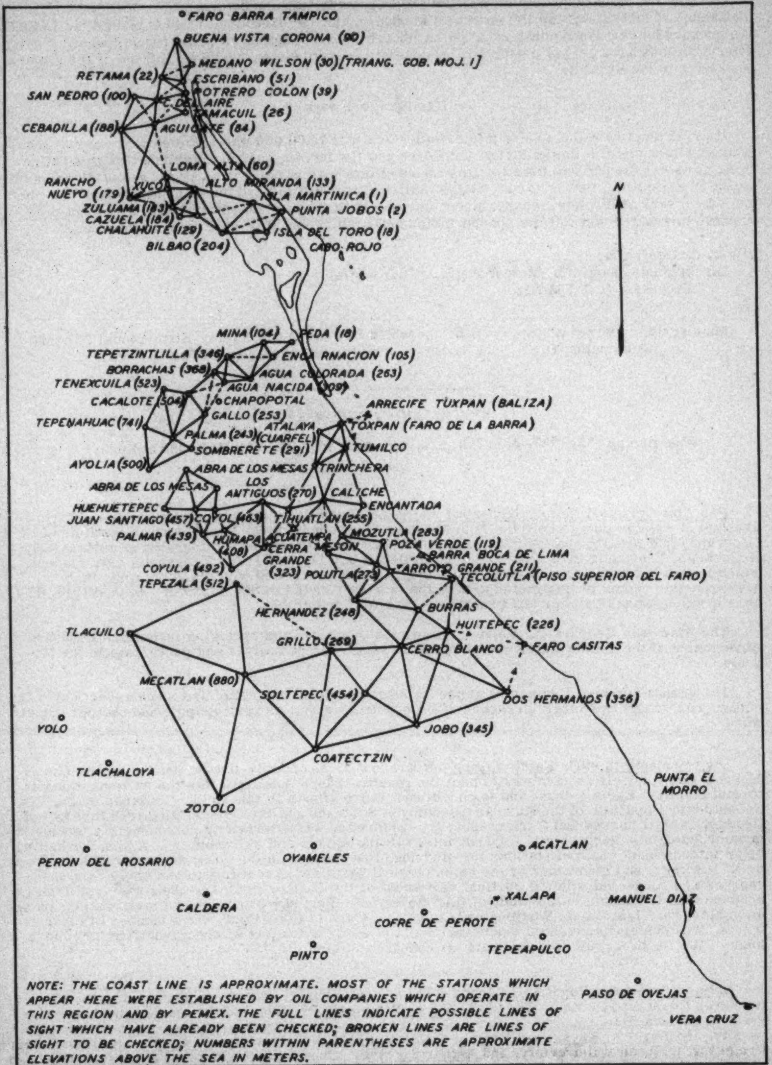
It has been possible to confirm that the provisional difference of altitude between the Atlantic and Pacific Oceans obtained by the precise leveling from Vera Cruz to Acapulco, mentioned in round numbers in the preceding report and published in the Transactions, American Geophysical Union, 1944, page 263, should be modified on account of a correction in the computation. We are not yet in a position to state the exact difference in level, in view of the fact that the investigation of the stability or movability of the intermediate bench mark established in the town of Tacubaya is still in progress.

The precise leveling in the basin of Mexico has been continued substantiating the fact of regular settlements of the soil, which in some places are as much as one centimeter per month.

Precise leveling has just been started along the International Highway from Mexico to Laredo, for the purpose of extending it for the whole length of that highway up to the boundary with the United States.

Gravimetric studies

There were no new gravity stations established in the past year nor during the months that have passed of the present year. With the results obtained recently, after having made the


FARO BARRA TAMPICO
BUENA VISTA CORONA (90)
MEDANO WILSON (30)[TRIANG. GOB. MOJ. I]
RETAMA (22)
ESCRIBANO (51)
SAN PEDRO (100)
POTRERO COLON (39)
C. DEL AIRE
TAMACUIL (26)
CEBADILLA (188)
AGUICATE (84)
LOMA ALTA (60)
RANCHO NUEYO (179)
XUCO
ALTO MIRANDA (133)
ISLA MARTINICA (1)
ZULUAMA (183)
PUNTA JOBOS (2)
CAZUELA (184)
CHALAHUITE (129)
ISLA DEL TORO (18)
BILBAO (204)
CABO ROJO
N
MINA (104)
PEDA (18)
TEPETZINTLILLA (346)
ENCARNACION (105)
BORRACHAS (368)
AGUA COLORADA (263)
TENEXCUILA (523)
AGUA NACIDA (109)
CACALOTE (504)
CHAPOPOTAL
ARRECIFE TUXPAN (BALIZA)
GALLO (253)
TEPENAHUAC (741)
ATALAYA (CUARFEL)
TUXPAN (FARO DE LA BARRA)
PALMA (243)
SOMBRERETE (291)
TUMILCO
AYOLIA (500)
ABRA DE LOS MESAS
TRINCHERA
ABRA DE LOS MESAS
LOS ANTIGUOS (270)
CALICHE
HUEHUETEPEC
ENCANTADA
JUAN SANTIAGO (457)
COYOL (463)
TIHUATLAN (255)
MOZUTLA (283)
PALMAR (439)
HUMAPA (408)
ACUATEMPA
CERRA GRANDE (323)
MESON
POZA VERDE (119)
BARRA BOCA DE LIMA
COYULA (492)
POLUTLA (273)
ARROYO GRANDE (211)
TECOLUTLA (PISO SUPERIOR DEL FARO)
TEPEZALA (512)
HERNANDEZ (248)
BURRAS
HUITEPEC (226)
TLACUILO
GRILLO (269)
CERRO BLANCO
FARO CASITAS
MECATLAN (880)
SOLTEPEC (454)
DOS HERMANOS (356)
YOLO
JOBO (345)
COATECTZIN
TLACHALOYA
PUNTA EL MORRO
ZOTOLO
ACATLAN
PERON DEL ROSARIO
OYAMELES
MANUEL DIAZ
CALDERA
XALAPA
COFRE DE PEROTE
TEPEAPULCO
PINTO
PASO DE OVEJAS
VERA CRUZ

NOTE: THE COAST LINE IS APPROXIMATE. MOST OF THE STATIONS WHICH APPEAR HERE WERE ESTABLISHED BY OIL COMPANIES WHICH OPERATE IN THIS REGION AND BY PEMEX. THE FULL LINES INDICATE POSSIBLE LINES OF SIGHT WHICH HAVE ALREADY BEEN CHECKED; BROKEN LINES ARE LINES OF SIGHT TO BE CHECKED; NUMBERS WITHIN PARENTHESES ARE APPROXIMATE ELEVATIONS ABOVE THE SEA IN METERS.

Fig. 5--Sketch showing the topographic triangulation project of the coast of Vera Cruz and its junction with the geodetic triangulation of the Sierra de Puebla

corrections for topography and isostasy at the 68 gravity stations determined by this Office, the Geographical Institute of the University of Mexico, under the direction of RITA LÓPEZ de LLERGO, has prepared a new isoanomaly map, which, though still incomplete in some regions where gravity determinations have not yet been made, represents, nevertheless, the general trend of the gravity anomalies in the Republic.

Cartographic work

The planimetry of the map of Jalisco in the scale of 1:100,000 was completed, the aerial photographs obtained by the United States Air Force and the terrain control established by this Office being used. At the present time the contouring of this map is being done by the use of direct methods of configuration, that is to say, by the outline of the profiles and the interpretation of the contours by means of the stereoscope, since, on account of the present state of war, it has not been possible to acquire some of the special instruments which would be used in analogous cases.

Oficina de Geografía,
Direccion de Geografía, Meteorología, e Hidrología,
Tacubaya, D. F., Mexico

(Manuscript received August 1, 1945; presented by title at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until May 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 444, 455, 456, 458, 459, 460 and 462)

NOTES

Pan American Institute of Geography and History and Pan American Consultation on Cartography--It was the plan to hold the Fourth General Assembly of the Pan American Institute of Geography and History and the Third Pan American Consultation on Cartography simultaneously in Caracas, Venezuela, from November 28 to December 11, 1945. The Venezuelan Government, which issued the invitations to these meetings, desires to proceed with plans but finds that arrangements cannot be completed to hold the meetings on the dates indicated. Accordingly, they have been postponed indefinitely, probably until next April or May.

The American Geophysical Union is among the organizations receiving invitations from the Government of the United States of Venezuela to send representatives and participate in the program.

The agenda are broad, covering geodetic, seismological, magnetic, and some aspects of oceanographic and hydrologic branches of geophysics, as well as cartographic and photogrammetric work.

Soviet scientists study Earth's crust--Representatives of forty-five scientific institutions of Moscow and other cities have met to pool the results of their research into the movement and deformation of the Earth's crust and to coordinate future efforts in this field. Convened by the Seismological Institute of the Russian Academy of Sciences and the Central Research Institute of Geodesy, Aerial Survey and Cartography, the conference was attended by seismologists, geologists, geomorphologists, geophysicists, geodesists, volcanologists, and astronomers. A plan for setting up an international chain of stations for studying slow changes in the force of gravity was proposed by N. Pariisky, an astronomer of the Seismological Institute. According to his hypothesis, these changes are connected with the vertical movement of the Earth's crust and their systematic measurement will contribute to the study of this movement. Pariisky proposes that such stations be set up in Moscow, Vladivostok, Washington, Greenland, Cape of Good Hope, and a number of other points. The conference elected a permanent commission of leading scientists studying the movement of the Earth's crust to coordinate all research in the field.

National Research Council of Canada--Three new members have been appointed to the National Research Council of Canada. These are Percy Bengough, President of the Trades and Labor Congress of Canada, Paul Gagnon, Director of the Department of Chemical Engineering at Naval University, and David A. Keys, Professor of Physics at McGill University. J. A. Gray, Science Research Professor at Queen's University, and Arthur Surveyer, Consulting Engineer of Montreal, have been reappointed.

Transactions, American Geophysical Union Volume 26, Number III December 1945

PROGRESS-REPORT ON SEISMOLOGICAL ACTIVITY OF THE UNITED STATES COAST AND GEODETIC SURVEY, 1944-1945

F. Neumann

The general seismological program of the Coast and Geodetic Survey continued without serious interruption although some branches of the work suffered through expanded programs in other branches.

Teleseismic work--The Survey continued to publish teleseismic results for 24 stations of which ten may be classed as independent, ten as cooperative, and four as Bureau stations. In addition, the Lake Mead Seismological Party operated five stations in the Boulder Dam, Shasta Dam, and Grand Coulee Dam areas with the cooperation of the United States Bureau of Reclamation. Five of the 24 stations previously named are in foreign countries. The successful operation of this large group of stations was due in large measure to the aid given by university officials, Weather Bureau personnel, personnel of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and of the Smithsonian Institution, representatives of the Greenland Government in the United States, and officials of the Panama Canal. Through the cooperation of Science Service, the Jesuit Seismological Association and many individual stations, 31 immediate epicenter-determinations were reported between June 1, 1944, and May 30, 1945.

Instruments at stations of the Survey in the western part of the United States were overhauled during the annual inspection of the Chief of the Seismological Field Survey which has headquarters in San Francisco. Assistance was also given to some stations outside of the Survey group. The station at East Machias, Maine, was discontinued.

A Wenner seismograph and a NEUMANN-LABARRE vibration-meter were lent FRED KELLER, Sr., of New Kensington, Pennsylvania, for tests with the electronic visual recorder developed by him [see Trans. Amer. Geophys. Union, 1944, Part II, pp. 304-309, 1944]. In San Francisco, Professor BYERLY has been operating a NEUMANN-LABARRE vibration-meter at one of his stations to compare its performance with that of other seismographs.

Sites for proposed seismograph-stations were tested with instruments at the College of the City of New York and at State College, Pennsylvania. As a result of these tests it was possible to recommend definite types of instruments for future installations.

A special investigation of earthquakes recorded in the Lake Mead Area revealed a definite relation between earthquake clusters and the local fault-system. These in turn were found related to changes of level occasioned by the increased water-load. The geographic positions of three Lake Mead stations were determined by triangulation in order to obtain more accurate locations of local shocks.

Copies of seismograms obtained at the time of the Cornwall-Massena earthquake of September 5 were supplied to the Dominion Observatory at Ottawa, Canada, to aid in a special study of the earthquake. Similarly, copies of seismograms of the destructive shock at San Juan, Argentina, on January 15, 1944, were furnished to the National Observatory at La Plata. Records of the seismograms of the great Japanese submarine earthquake of December 7, obtained at the Strasbourg University, were received through Army liaison channels. This shock registered amplitudes at distant stations greater than the disastrous Tokyo earthquake of 1923.

In response to a circular request from the Acting Secretary of the International Seismological Association, efforts were made to resume the exchange of seismological records with that office and with other foreign countries.

Information-service--The regular earthquake-information service on the Pacific Coast and in the western mountain region was maintained, but there is little doubt that the number of active cooperators is dwindling due to the inability to maintain the necessary contacts. Efforts will be taken

to remedy this situation after the war since it is becoming increasingly apparent that such a questionnaire service plays an important part in locating many weak earthquakes which cannot be located instrumentally.

The area affected by the Cornwall-Massena earthquake of September 5, 1944, was canvassed and the information turned over to the Dominion Observatory at Ottawa, Canada, for use in its report on the shock. The Jesuit seismological stations at St. Louis, Missouri, and Weston, Massachusetts, continued to operate in their special areas in the collecting of earthquake-data.

The late Professor HARRY FIELDING REID'S seismological files containing much original material were turned over to the Coast and Geodetic Survey for permanent storage.

Strong-motion-work--Forty-two accelerographs, six displacement-meters, and eleven WEED strong-motion seismographs are being operated by the Survey, most of them in the Pacific Coast Area. The accelerograph at Bozeman, Montana, has been temporarily removed. Four accelerographs removed from stations on the Pacific Coast and in the western mountains for use in South America will be replaced by new instruments.

Strong-motion records of ten earthquakes were obtained but only one shock was strong enough to be considered of moderate intensity. Two shocks, three hours apart, were recorded in the Los Angeles Area on June 18, 1943, at six local stations.

The application of torsion-pendulum analyses to accelerograph-records continues to receive considerable attention on the part of those interested in the design of earthquake-resistant structures. Recent investigations indicate that the foundation-factor plays a vital part in determining the response of buildings to earthquake-motion and it must be taken into account in analytical studies before rational conclusions can be reached. A committee of New Zealand engineers requested a report on recent progress in engineering-seismological research in the United States.

The American Standards Association, cooperating with the National Bureau of Standards, is nearly ready to issue a publication on building-codes which includes a section on the earthquake-problem.

Plans are being made to transfer one of the tilt-meters on the University of California Campus at Berkeley to the Long Beach Area where marked changes in elevation have been observed within the last few years.

Vibration-work--A special party of Survey personnel was sent to Ross Dam in the northern part of the State of Washington to record the magnitude of the vibrations caused by blasting two large diversion tunnels through solid granite. The purpose was primarily to determine whether the vibrations might be dangerous to the setting and bonding of concrete being placed in connection with a project to double the height of the present dam. The observational program was largely exploratory and valuable information was obtained regarding the type of equipment needed in this type of high-frequency work.

Vibration-observations were made at Grand Coulee Dam in order to investigate the effect of vibrations set up by the falling water, on observations recorded at the seismograph-station nearby

Instruments--A NEUMANN-LABARRE vibration-meter was fitted with special foot-screws and remote control in an experiment to read the amplitudes of microseisms visually, especially during microseismic storms.

An electronic convertor was tested over a period of about ten months to determine its reliability as a source of 110-volt alternating current for the operation of seismograph-recorders from a battery-source. The units were found to have an exceptionally long life with fairly steady frequency-output. The frequency-characteristics can be maintained uniform by the control of the temperature of the vibrating-reed. The unit is considered satisfactory as a control for seismograph-recorders in locations using unreliable commercial power.

Two new pendulum-clocks were received and were tested for operation of the four definite time-circuits provided. The seconds contact will provide for the speed-control of small direct-current motors.

The instruments installed at Boulder Dam, Shasta Dam, and Grand Coulee Dam about a year ago are giving satisfactory service.

A model of a galvanometric seismometer was furnished the College of the City of New York to prepare shop drawings prior to the award of a contract for the construction of two of the instruments for the College.

Two additional high-magnification NEUMANN-LABARRE vibration-meters were constructed in the instrument-shop of the Coast and Geodetic Survey. Four more are in process of construction.

South American Project--FRANKLIN P. ULRICH, the representative of the Coast and Geodetic Survey on this work, has practically completed this year's program of visiting the various countries of South and Central America. The object of the project is to encourage expansion of seismological work where needed and to improve cooperation between the countries of the Western Hemisphere. The following countries are being visited this year: Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Nicaragua, Panama, Peru, Uruguay, and Venezuela. The program has been highly successful and quite a number of countries are acquiring instruments, inaugurating questionnaire programs, and preparing earthquake-catalogues. Last year, accelerographs were installed at Santiago, Chile, and Lima, Peru. This year, one each was installed at Guayaquil, Ecuador, and Bogota, Colombia. To date only two light shocks have been recorded on the Lima instrument.

FEDERICO GREVE S., who is in immediate charge of the seismological work in Chile, is planning to install a seismograph in the Punta Arenas Area near Cape Horn. The need for a station in this area was stressed in a resolution passed at the Meeting in 1939 of the International Seismological Association in Washington.

Parícutin Volcano Project--AUSTIN E. JONES and FRED KELLER, Jr., geophysicists of the Coast and Geodetic Survey, were assigned early this year to install seismological equipment in the Parícutin Volcano Area and to repeat some of the magnetic observations made by R. R. BODLE and N. C. STEENLAND in 1943. This work is being carried out as a part of the broad scientific and cultural program sponsored by the Interdepartmental Committee of the State Department. A seismograph has been established near the base of the Volcano in a special shelter. Activity of a local microseismic character is being recorded. A report covering work in 1943 was issued in 1944.

Miscellaneous--Microseismic investigations directed toward a better understanding of the relation between amplitude-variations and barometric lows are continuing. An expanded program of sea-wave and weather-observation is being planned.

Publications--"United States earthquakes, 1942," one of the annual seismological publications of the United States Coast and Geodetic Survey, was issued in 1944.

The Seismological Bulletins have been issued through June, 1943. In that year the Bulletin was changed from a monthly to a quarterly report.

"Abstracts of earthquake reports for the Pacific Coast and Western Mountain Region" were issued through June, 1944.

The quarterly progress-reports on strong-motion work are current.

United States Coast and Geodetic Survey,
Washington 25, D. C.

(Manuscript received May 30, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until May 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 455, 456, 458, 459, 460, and 462)

NOTES

Earthquakes in September and October 1945--No earthquake of importance was reported from any land area. Fourteen strong shocks were located provisionally from instrumental data obtained through the cooperation of the United States Coast and Geodetic Survey, Science Service, the Jesuit Seismological Association, and a special group of seismological stations. The following list includes a shock that occurred in August, but not reported in the Transactions covering that month [see p. 297]. The times listed are Greenwich Mean Time.

	h	m	
August 29	10	22.6	New Hebrides Islands, 14°S, 166°E.
September 2	11	53.9	Eastern Mediterranean, 34.0°N, 30.0°E.
September 13	11	17.0	Central Chile, 34°S, 70°W. Destructive.
September 14	2	02.4	Mid-Atlantic Ocean, 7.0°N, 38.8°W.
September 26	14	26.8	East of Puerto Rico, 18.9°N, 62.4°W.
September 28	22	24.1	Off northern California, 41.7°N, 126.9°W.
October 7	13	23.4	Off San Salvador, 12.3°N, 89.0°W.
October 9	14	36.6	East of Hokkaido, Japan, 43°N, 150°E.
October 11	16	52.7	Oaxaca, Mexico, 17°N, 97°W.
October 15	8	01.2	Off Yakutat Bay, 59.0°N, 140.0°W.
October 16	16	03.1	Celebes Islands, 0.5°N, 126°E.
October 25	14	58.5	Kamchatka, 56.1°N, 162°E.
October 27	11	24.5	Guatemala, 15°N, 91°W.
October 29	10	54.3	Off British Columbia, 52°N, 131°W.

Section of Engineering Geology, United States Geological Survey--The Section of Engineering Geology of the United States Geological Survey, under E. B. Eckel, will soon transfer its headquarters to Denver, Colorado, to facilitate cooperation with the Bureau of Reclamation.

Transactions, American Geophysical Union Volume 26, Number III December 1945

REPORT OF THE COMMITTEE ON EXTENDED FORECASTING, 1944-1945

J. Namias, Chairman
R. D. Elliott H. W. Norton Harry Wexler
H. C. Willett

The Committee on Extended Forecasting was formed in 1944. The first annual report [Trans. Amer. Geophys. Union, 1944, Part III, p. 480] included a statement of the functions of the Committee.

During the past year the Committee answered two requests relating to long-range forecasting--one from a civilian agency and the other from a military agency of the Government.

At a meeting held on May 16, 1945, at which all members except Dr. Willett were present, it was decided that the Committee would shortly take steps to prepare an up-to-date bibliography on long-range forecasting. Initially this bibliography would list papers and reports on the subject which have been prepared during the past five years and, later, the literature of earlier years.

It was also decided that when the pressure of war-time activities ceases, permitting more time and personnel, the Committee should prepare a chapter summarizing those methods of long-range weather-forecasting currently being used. In this report some attempt would be made to interrelate and compare various methods and to define their limitations.

The following recommendations were made:

(1) That all currently classified material dealing with long-range forecasting and research be made unclassified as soon as security permits.

(2) That all organizations concerned attempt to make public the services rendered and techniques used by various groups engaged in long-range forecasting as soon as security permits.

(3) That every attempt be made to maintain the current network of surface and upper-air data over the Northern Hemisphere and to expand it when possible throughout the world.

(4) That the file of Northern Hemisphere weather-maps, so helpful in the present war, be brought up to date after the war with the use of all possible observational data.

(5) That data from the Northern Hemisphere weather-maps be entered on punch-cards in a centralized library so that a ready means will be available for processing data in terms of desired averages.

(Manuscript received June 6, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., June 1, 1945; open for discussion until May 1, 1946.)

REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

(See also pp. 346, 352, and 358)

REVIEWS AND ABSTRACTS

HUGH DUNCAN GRANT: Cloud and weather atlas. xviii + 294 pp., incl. 176 illus., 14 chts. and tables, index; 7-1/2 × 10 in. New York, 1944.

This book is chiefly an assembly of a wide range of striking photographs of clouds. Though the author himself made none of the pictures he has proven to be a capable procurer from many sources: American, European, and African. Meteorologists and others will find these large and finely reproduced photographs interesting and beautiful. There are many excellent pictures, including one of an airplane cirrus trail (p. 47). Ordinary skies, which are difficult to photograph, are but sparsely represented. Although only 16 of the 159 photos of clouds are listed as "Aerial views," there are 36 others taken from airplanes and about a score more of photos from mountains. This emphasis on photos of clouds from aloft is in keeping with the constantly increasing number of persons who see clouds from above as well as from below. The other groupings and numbers of photographs are: "Clouds classified," 68; "Clouds and sun," 6; "Storm clouds,"(including a sequence of four on progress of thunderstorms) 14; "Frontal cloud formations," 10; "Weather forecasts from clouds," 33 (two upside down, pp. 185, 191); "Fog," 3; and "Optical appearances," 11.

It is particularly unfortunate that some 20 per cent of the legends to such a fine set of pictures are, even with respect to genus, not in conformity with the International nomenclature that the book professes to illustrate. For example, a very good Cc or fine Ac sky is labeled "Cirrus undulatus" (p. 46); an airplane close-up of a cumulus cloud, the top of which is fraying out slightly but is definitely not fibrous, is called "Cirrus densus, or false cirrus" (p. 48); a bright picture of high broken clouds, mostly Ci and Ac, is labeled "Nimbostratus" (p. 65). Ac lent is titled "Altostratus. 'Whirling altostratus'"(p. 58). An ordinary Cu, not very large or dark and with no signs of cirriform top or of precipitation, bears the legend: "Cumulonimbus. The thunderhead which harbors thunder, hail, and powerful drafts. Note the false cirrus breaking off from the top, and the flat base of the thunder cloud"(p. 78). Dates and places of a few pictures are given, but for the most part when dates are mentioned the places are omitted. It is dangerous to take an undated picture, as the author frequently does, and say what weather will usually follow. Thus, one of the reviewer's photos of Ac in a lateral sky that was followed by fair weather bears the legend, "Active, or transforming altocumulus. Usually precedes rain." (p. 55). The length of each legend is determined by the space available under the picture, making it impossible for the author to say enough where he has but one or two lines available, and difficult not to pad where he has some 15 lines to fill.

The general text, occupying half the book, is separate from the cloud plates and legends. It is more or less of a meteorological text-book of non-technical nature, sprinkled, however, with minor inaccuracies. Chapter 1 describes "How clouds are formed;" and Chapter 2, "Cloud regions and beyond.""Cloud classification" is the subject of Chapter 3. This is well handled and up to date, though some would not find the author's brief annotations to the cloud genera acceptable. In Chapter 4, information on the heights of clouds is presented in tabular form, with brief indications of aviation weather associated. Chapter 5, on "Movements of the air--cyclones and anticyclones," presents the general and secondary circulations and related cloud systems and sequences, the foehn wind, katabatic wind, wind-barometer indications, tornadoes, thunderstorms and other local disturbances, and miscellaneous information. Chapter 6, "Air-mass and frontal analysis," is confusing, with three different definitions of "front"on the first two pages (pp. 145, 146), in the sense of an air-mass, a line on the Earth's surface, and a surface separating air-masses, and with numerous minor errors sprinkled over its 11 pages. "The significance of clouds for tomorrow's weather" is the topic of short Chapter 7. Chapter 8 is a brief statement on "Fog and visibility." Chapter 9 is devoted to "Weather signs and optical appearances." The proverbs are well chosen, and the optical phenomena presented at some length (15 pp.) clearly and interestingly. "Variations of cloud color," Chapter 10 (4 pp.), is also excellent. "Cloud codes and symbols" are presented in Chapter 11, along with the more commonly used International meteorological symbols, states of the weather (ww), and United States weather map symbols, with a sample map. "World aspects," Chapter 12, includes cloudiness and sunshine duration, and temperatures by hemispheres. Chapter 13 is "Pageant of the sky--a summary." Chapter 14, the last chapter, has five pages on "Aerial views of clouds," mostly "Clouds in flight" by Peter E. Kraght.

A feature of this book (by a Britisher) is the wealth of references to British literature. To the American meteorologist these British references have distinct value. To sum up, though the text is uneven in quality and the legends disappointing, Mr. Grant's book is outstanding for the variety and number of the cloud photographs so finely reproduced on a large scale.

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Transactions, American Geophysical Union Volume 26, Number III December 1945

MAGNETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY FROM APRIL 1944 THROUGH MARCH 1945

O. W. Swainson

The facilities of the Section of Geomagnetism of the United States Coast and Geodetic Survey were devoted largely to obtaining and furnishing magnetic information for charts for use by the military services.

The close cooperation maintained in former years with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington was continued, by temporary loans of certain field and observatory instruments and by exchange of data obtained in repeat surveys of the United States, Alaska, Central America, South America, and elsewhere.

Magnetic surveys

In other American Republics--The program of magnetic repeat-observations in other American Republics, which was begun in November, 1941, continues. This work is being executed in cooperation with the Interdepartmental Committee on Cultural and Scientific Cooperation, United States Department of State. The third season's work, which began in February, 1944, and ended in June, 1944, included stations in Brazil, Chile, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, and Peru, extending as far south as Punta Arenas, Chile, on the Straits of Magellan. The observer compared his instruments with those at the observatories at Huancayo (Peru) and Vassouras (Brazil). Diurnal variation observations for declination and horizontal intensity were made at Iquitos, Peru.

The fourth season's work began in February, 1945, when an observer went to Mexico to make additional observations. He later went on to the Galapagos Islands, where he made diurnal variation observations, and to South America.

In February, 1945, other observers began a series of special observations in the vicinity of Parícutin Volcano in Mexico to determine whether any changes of the magnetic field may be attributed to volcanic activity.

In the United States--The repeat-observations required for the compilations of the 1945 isomagnetic charts of the United States were started in 1943 and were completed in November, 1944, some 200 stations having been occupied.

A partial repeat-survey of Alaska was made in 1944. It was not possible to occupy all of the stations that were occupied in 1939-40, but the stations on the Arctic coast were included. The observations have given valuable information on secular change.

As usual, a considerable number of observations of the magnetic declination were made by parties of the Survey which were not engaged primarily in magnetic work. These included observations made in and around New York Harbor, at many airports throughout the United States, and in connection with hydrographic surveys along the coasts of the United States and Alaska, even as far as the outer Aleutians.

Special observations were made in several areas for the Navy and other war agencies.

Table 1 summarizes the magnetic observations made during the year.

Work in the office

As in the previous year, magnetic data were furnished to nearly every agency of the Government which is engaged in making maps. The three-hour-range indices, K, were furnished daily to the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and to several Governmental agencies.

Table 1--Magnetic stations occupied April 1944 to March 1945

State or region	Repeat-stations				Other stations	Totals
	Old		New			
	D only	Complete	D only	Complete		
Alabama	...	1	...	...	...	1
Arizona	...	1	...	...	3	4
Arkansas	...	1	...	...	...	1
California	...	5	...	2	5	12
Colorado	...	4	...	...	4	8
Delaware	...	...	...	...	1	1
Georgia	...	...	...	1	3	4
Idaho	...	1	...	1	1	3
Illinois	...	...	...	1	1	2
Indiana	...	1	...	...	...	1
Iowa	...	...	...	...	1	1
Kansas	...	4	...	...	3	7
Kentucky	...	2	...	...	1	3
Louisiana	...	...	...	1	2	3
Maine	6	...	1	...	4	11
Massachusetts	1	...	...	...	2	3
Minnesota	...	4	...	...	1	5
Mississippi	...	1	...	3	...	4
Missouri	...	3	...	...	2	5
Montana	...	9	...	...	10	19
Nebraska	...	3	...	...	4	7
Nevada	...	5	...	1	1	7
New Jersey	1	...	...	...	6	7
New Mexico	...	3	...	...	1	4
New York	1	...	1	...	8	10
North Carolina	...	...	...	...	1	1
North Dakota	...	4	...	1	4	9
Ohio	...	...	...	...	1	1
Oklahoma	...	1	...	...	...	1
Oregon	...	4	...	1	2	7
Pennsylvania	...	...	...	...	2	2
Rhode Island	1	...	...	...	1	2
South Carolina	...	...	...	...	2	2
South Dakota	...	2	...	2	3	7
Tennessee	...	...	...	...	1	1
Texas	...	3	...	1	8	12
Utah	...	2	...	1	3	6
Vermont	1	...	...	...	18	19
Virginia	...	...	...	...	3	3
Washington	...	5	...	1	2	8
Wisconsin	...	3	...	...	...	3
Wyoming	1	3	...	2	6	12
Alaska	1	16	1	2	54	74
Hawaii	...	...	...	...	1	1
Marshall Islands	...	...	...	...	1	1
Mexico	...	...	...	2	...	2
Guatemala	...	5	...	1	...	6
Honduras	...	2	...	2	...	4
Nicaragua	...	1	...	3	...	4
Chile	...	1	...	3	...	4
Ecuador	...	...	...	2	...	2
Peru	...	2 [a]	1	3	...	6
Totals	13	102	4	37	177	333

[a] Includes standardization at Huancayo.

Work continued on preparation of a series of 43 isogonic charts to cover the Earth, on a scale of 1:5,000,000.

During the year, preparation of manuscript and all proof-reading were completed for a new publication "Magnetism of the Earth." It supersedes "The Earth's magnetism," which was issued in 1925. Most of the material in the older publication has been carefully revised in the light of the latest information, and many portions have been considerably enlarged, especially the chapter on transient variations. The publication will be for sale by the Government Printing Office.

Work was started on the manuscript of "Magnetic declination in the United States in 1945." It is expected that the publication will be issued early in 1946.

A special "Report on magnetic survey and seismological observations, vicinity Parícutin volcano, in Michoacan State, Mexico, May-July, 1943," was issued by offset lithography. A summary of the results has already been reported to the Section of Volcanology of the American Geophysical Union [see 1 of "References" at end of this report].

The report mentioned last year dealing with the repeat observations in other American Republics has been enlarged to include work done in 1944, but has not yet been issued.

The preparation of four volumes of results for observatories was completed during the year, for reproduction by offset lithography. These volumes are for Cheltenham 1935-36, Tucson 1935-36, Tucson 1937-38, and the special observatory operated during the Polar Year (more exactly, from October, 1932 through March, 1934) at College, near Fairbanks, Alaska.

"Alaska magnetic tables and magnetic charts for 1940" is in press. It also is being reproduced by offset lithography. Its issue, as well as that of the observatory results, is delayed by demand on the roto-presses for printing charts needed by the Army and Navy.

The Section of Geomagnetism continued to occupy the enlarged quarters mentioned last year. The New York Computing Office continued to have a small unit processing magnetic records, although the personnel of the unit was reduced from five to three in January, 1945.

Instrumental program

Good progress has been made on the development of instruments for declination recording stations. These instruments are on test at Cheltenham Observatory.

In cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a new induction-magnetometer has been constructed and standardized at Cheltenham. With this instrument it is possible to determine horizontal, vertical, and total intensity, as well as magnetic inclination and magnetic azimuth. Its performance during the tests at the Observatory has been very satisfactory.

Precision potentiometers, standard cells, and other electrical-measuring instruments have been calibrated by the National Bureau of Standards.

Observatories

The five magnetic observatories of the Survey continued in operation without serious interruption.

Cheltenham, Maryland--Routine operation of three magnetographs continues. Field instruments of the Survey and of other agencies engaged in magnetic work have been standardized here. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington cooperates in the maintenance of international magnetic standards at this observatory.

Honolulu, Territory of Hawaii--There are occasional but unavoidable mechanical disturbances in the vicinity of the observatory, but performance of the magnetograph has been reasonably satisfactory. Definite steps have been taken to secure a more favorable site.

San Juan, Puerto Rico--Performance of the magnetograph has been reasonably satisfactory during the year.

Sitka, Alaska--Two magnetographs (sensitive and insensitive types) are maintained in operation.

Tucson, Arizona--Normal operation of the magnetic observatory and the cooperative work with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on atmospheric potential-gradient and positive and negative air-conductivity have been continued. The magnetic moment of the long magnet of the magnetometer continued to increase, but at a reduced rate [2].

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[2] J. H. NELSON and J. B. CAMPBELL, Additional data on the spontaneous increase of a magnetic moment, Trans. Amer. Geophys. Union, v. 26, pp. 379-380, 1945.

U. S. Coast and Geodetic Survey,
Washington 25, D. C.

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(See also pp. 338, 357, 366, 378, 388, 392, and 414)

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KAARE MÜNSTER STRØM, Heat in a south Norwegian lake, Studies on Lake Eikeren during the years 1934 and 1935, Geofys. Pub., Oslo, v. 16, no. 3, 22 pp., 1944.

EINAR TØNSBERG and KAARE LANGLO OLSEN, Investigations on atmospheric ozone at Nordlyobservatoriet, Tromsø, Geofys. Pub., Oslo, v. 13, no. 12, 39 pp., 1944.

Transactions, American Geophysical Union Volume 26, Number III December 1945

REPORT OF COMMITTEE ON EVAPORATION AND TRANSPIRATION, 1944-1945

H. G. Wilm, Chairman
C. W. Thornthwaite, Assistant Chairman

E. A. Colman
N. W. Cummings
A. R. Croft
H. T. Gisborne
S. T. Harding
A. H. Hendrickson
M. D. Hoover
I. E. Houk
J. Kittredge
C. H. Lee
C. -G. Rossby
T. Saville
C. A. Taylor

During the past year the work of this Committee has suffered from personnel shortages and the pressures of wartime duties, so that a number of members--including the Chairman--are unable to report on current progress. In addition, Messrs. HOUK, SAVILLE, and TAYLOR have suggested that they be released at least temporarily from membership on the Committee, as their present work is not associated with this Committee's research field.

In view of wartime handicaps, it is gratifying that several of the members have been able to prepare reports on active research in evaporation and transpiration. Statements submitted by these men are presented below.

E. A. COLMAN (California Forest and Range Experiment Station)--The California Forest and Range Experiment Station of the United States Forest Service is seeking to measure evapotranspiration on chaparral-covered watersheds of the San Dimas Experimental Forest by two methods. One involves the use of lysimeters for comparing the evapotranspiration characteristics of the important chaparral plants under closely controlled environmental conditions. The problems and difficulties of the lysimeter approach have received attention in earlier reports of the Committee. Solution of some of the problems is still being sought.

The other method entails periodic sampling of field soil-moisture for the measurement of water losses from the soil. Since 1940 weekly or biweekly samplings have been made in field-plots varying in number from nine to 20. This work supplements a study of the soil-moisture regimen at North Fork in the lower Sierra Nevada Mountains which is being carried on by the Forest Experiment Station.

Although the San Dimas data are still in process of being analyzed, they have already yielded interesting and suggestive results. These are presented here in the hope that they may prove useful to others engaged in similar kinds of investigation.

(1) Moisture-sampling in virgin mountain soils in southern California is rather unsatisfactory because of the variability in soil-conditions found within very small, apparently uniform areas. Chronologic plotting of the water-content of a five-foot deep block of soil in such an area almost invariably shows a saw-tooth pattern that very definitely discourages any attempt at highly accurate measurements of water-storage or water-loss. The trends are shown satisfactorily, but it has been found impracticable to calculate the water stored at any time more accurately than to the nearest half inch. This variability is attributed to the lack of uniformity in characteristics of soil, vegetation, and exposure. Perhaps the most promising way to increase the accuracy of measurements of soil-water storage lies in the employment of one of the electrical or manometric instruments being developed for soil-moisture determination. Such instruments would not only permit the continuous measurement of moisture at one point in the soil but would greatly reduce the amount of work necessary for these measurements. No entirely satisfactory instrument is yet available but there is good likelihood that this is not to be a permanent situation.

(2) Under conditions in southern California, in which the water-table is beyond the reach of plant roots, definite and reproducible annual cycles of soil-water storage are observed. The upper limit of water-storage is set by the field-capacity, except for very short periods following large storms. If sufficient rain falls during the rainy season, the soil-reservoir is eventually filled to its field-capacity storage, permitting rain which falls subsequently to percolate through it. The

permanent wilting-point, as determined by the classic "sunflower-method," provides a satisfactory estimate of the minimum water-storage attained by the soil before the end of the dry season each year. Only in the top foot, where direct evaporation is important, does soil-water storage reach values significantly less than the wilting-point.

(3) The soil thus has a definite moisture-range, and the problem remaining is to find under what conditions variations within this range take place. It is found that there is a considerable evapotranspiration loss during the interstorm periods of the rainy season. More rain is therefore required to raise soil-water storage from the wilting-point to field-capacity than is indicated by the difference in soil-water storage between these two values. The characteristics of rainy seasons and of individual storms play a part in determining the amount of rain required, for a single large storm may replenish the soil-reservoir without loss by evaporation while a series of small showers may result in a large percentage of such loss. It is proposed that we may characterize or "evaluate" a rainy season in terms of the relationship between rainfall received and rainfall required to raise soil-water storage from summer dryness to field-capacity.

(4) In connection with field-moisture studies, a recent paper by L. A. RICHARDS and L. R. WEAVER is of interest [Moisture retention by some irrigated soils as related to soil moisture tension, J. Agric. Res., v. 69, pp. 215-235, 1944]. In this paper the authors have shown a satisfactorily definite relationship to exist between the sunflower-determined wilting-point and the moisture retained by soil drained under a tension of 15 atmospheres. Numerous comparisons of these two methods have been made on the San Dimas Forest during the last two years, and the findings of RICHARDS and WEAVER have been amply corroborated. The 15-atmosphere method provides an easy and rapid way to obtain a measure of the wilting-point. It should find wide use among students of soil and plant interrelationships.

A. R. CROFT (Intermountain Forest and Range Experiment Station)--Studies are being made of evapotranspiration loss from steep, drained slopes and from stream-channels at this Experiment Station's Wasatch Branch in northern Utah.

On drained slopes the study is confined to a north-facing site with aspen-fir cover and a south-facing site with low brush-cover, both at elevations of 7,000 feet. Losses are ascertained by periodic soil-moisture determinations year-long in watershed mantles six feet deep. Considering averages for two years (1942-43 and 1943-44) the moisture-content of the mantle at the south-facing site was reduced from 16.5 inches of water, at field-capacity about June 10, to 5.0 inches on September 30--a loss of 11.5 inches. At the north-facing site the mantle-moisture was reduced from 21.5 inches, at field-capacity about June 20, to 8.0 inches September 30--a loss of 13.5 inches. When summer rainfall of 1.4 inches in 1943 and 2.0 inches in 1944 is added to these amounts, average evapotranspiration losses of 13 and 15 inches are indicated at the south- and north-facing sites respectively.

Obviously these amounts will vary from place to place, depending on mantle-depth, and from year to year, depending on the amount of summer precipitation, most of which infiltrates into the mantle only to be lost again by evaporation and transpiration.

The values indicated do not represent total evapotranspiration loss because some water is lost by evaporation from snow and a small amount by transpiration during late spring from gravitational water while it is moving through the mantle.

The effect of plant-cover changes on evapotranspiration loss will be investigated at the sites of the present study.

The other phase of the study, loss of water by evaporation from streams and by transpiration of riparian vegetation, has been in progress only one year but results suggest that stream-flow is reduced between 25 and 30 per cent as a result of these factors. These values were obtained by observing stream-flow changes in relation to vapor-pressure changes during the summer, and to the fall of leaves in September.

N. W. CUMMINGS (San Bernardino, California)--A paper now in preparation [to be published in a forthcoming issue of the Transactions] is primarily a reply to objections that have been raised by two writers against the use of the BOWEN equation for the ratio of the two energy components. One of these was published in the Transactions by HOLZMAN in 1941 and deals with the location of the instruments. The other, which deals with radiative diffusivity, has not been published.

In the process of preparing the paper, a mistake in a previous paper was discovered. As a result, Tables (1) and (3) of "The evaporation-energy equations and their practical application," published by CUMMINGS in the Transactions in 1940 [pp. 512-522] need revision with respect to the average R for the lake, which turns out to be in the vicinity of 30 per cent, making the ratio of lake to Weather Bureau pan about 87 per cent.

J. KITTREDGE (University of California)--"Interception tests on mountain desert shrubs" is the title of a recent manuscript report by W. I. HICKS, Civil Engineer of the Bureau of Engineering of the City of Los Angeles. Artificial rainfall was applied by sprinkler to clumps of shrubs of Christmas berry, mountain mahogany, and chamise mounted on impervious platforms with arrangements to collect the water which ran off. The tests indicated that, in short rains of high intensity, the amount of rainfall retained on the shrubs long enough to affect quick runoff was small and unimportant. Stem flow averaged 25 per cent of the rates of precipitation.

C. W. THORNTHWAITE (Soil Conservation Service)--In the report of the Committee for 1943-44, I called attention to the need for distinguishing between potential evapotranspiration and actual evapotranspiration, and pointed out that the former term is equivalent to "consumptive use."

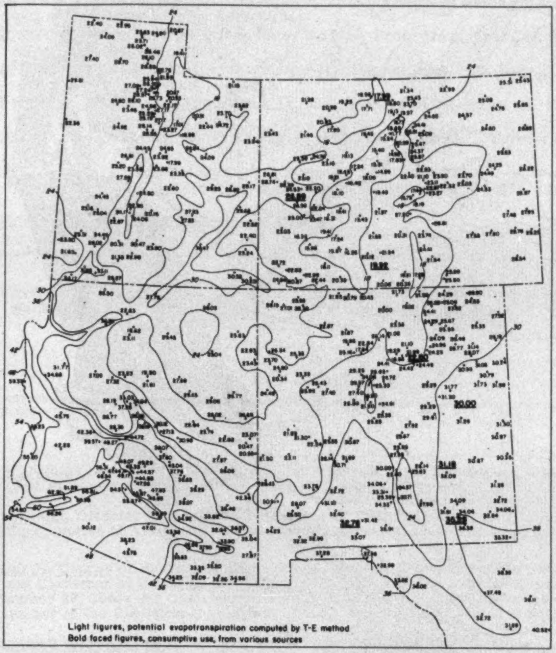
Light figures, potential evapotranspiration computed by T-E method
Bold faced figures, consumptive use, from various sources

Fig. 1--Average annual potential evapotranspiration in Utah, Colorado, Arizona, and New Mexico, in inches

Potential evapotranspiration is the water-loss that would occur if soil-moisture were constantly at the optimum level for maximum plant-growth. When the soil-moisture supply is at this level, the amount of water transpired by vegetation depends upon atmospheric factors alone, the most basic of which is solar radiation. As the soil-moisture supply diminishes, the tension with which it is held by the soil becomes progressively greater, and absorption by the roots becomes slower. When the tension rises to about eight atmospheres, the plants enter the permanent wilting-range and transpiration falls to a very low value. As the tension rises to fifteen atmospheres, the plants reach the

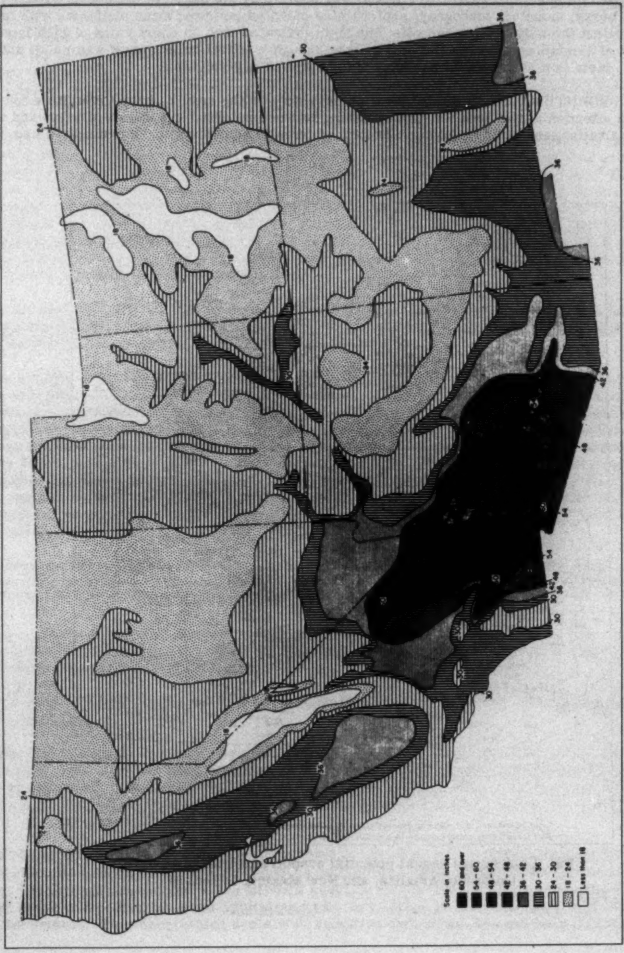

Fig. 2--Average annual potential evapotranspiration in southwestern United States

stage of ultimate wilting, where they are no longer able to withdraw water from the soil and transpiration ceases. Since the distribution of rainfall through the growing season rarely coincides with the changing need for water by the plants, almost everywhere soil-moisture is sometimes deficient. Thus the actual evapotranspiration is usually less than the potential.

Where supplementary water is required for successful agriculture, it is important to know the total amount of water the plants need for maximum growth. I have prepared two maps showing the average annual potential evapotranspiration in the southwestern United States. The first (Fig. 1), which includes the states of Utah, Colorado, Arizona, and New Mexico, gives the values of potential evapotranspiration as computed by the T-E method from temperature data of the various stations of the Weather Bureau. Also shown in bold-faced figures are determinations of "consumptive use" at several localities in Colorado and New Mexico, that I obtained from various sources. The second map (Fig. 2) gives the distribution of potential evapotranspiration in the six southwestern States. The quantity of water that would be used by vegetation, if it were available, varies from less than 18 inches in the mountains of California, Utah, and Colorado, to more than 60 inches in parts of Death Valley and Imperial Valley in California and the lower Gila Valley of Arizona.

It is suggested that the following articles are well worth study by anyone who is interested in the field of research of the Committee:

E. A. COLMAN, The dependence of field capacity upon the depth of wetting of field soils, Soil Sci., v. 58, No. 1, pp. 43-50, 1944.

G. H. HICKOX, Evaporation from a free water surface, Proc. Amer. Soc. Civ. Eng., v. 70, No. 8, pp. 1297-1327, 1944.

JOSEPH KITTREDGE, Estimation of the amount of foliage of trees and stands, J. Forestry, v. 42, No. 12, pp. 905-912, 1944.

JOSEPH KITTREDGE, Some quantitative relations of foliage in the chaparral, Ecology, v. 26, No. 1, pp. 70-73, 1945.

H. J. LUTZ, Soil conditions of picnic grounds in public forest parks, J. Forestry, v. 43, No. 2, pp. 121-127, 1945.

H. J. LUTZ, Determination of certain physical properties of forest soils (in two parts), Soil Sci., v. 57, No. 6, pp. 475-487, 1944; also v. 58, No. 4, pp. 325-333, 1944.

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(Manuscript received June 14, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until May 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 456, 458, 459, 460, and 462)

PERSONALIA

Robert W. Adams, Assistant Professor of Civil Engineering at Mississippi State College, died on October 13 at Pittsburgh, Pennsylvania.

Filip Åkerblom, Director of the Scientific Station at Abisko, Sweden, died on July 24, 1942. Prior to taking up duties at Abisko in 1934, he was Professor of Meteorology at the University of Uppsala.

Dr. Walter B. Cannon of Harvard Medical School, Foreign Secretary of the National Academy of Sciences and Chairman of the Division of Foreign Relations of the National Research Council, died on September 29, 1945. As Chairman of the Division of Foreign Relations, he had been an ex-officio member of the Executive Committee of the American Geophysical Union since 1942.

John Campbell Merriam, paleontologist and formerly President of the Carnegie Institution of Washington, died on October 30 after a long illness. At the time of his death, he was President of the Pan American Institute of Geography and History.

H. Wattenberg, former Chief of Staff of Meereschemisches Laboratorium der Universität, Kiel, Germany, died during a bomb attack on Kiel.

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 455, 458, 459, 460, and 462)

PERSONALIA

Word has come from Julius Bartels that he survived the bombardment and siege of Berlin, but that the Geophysical Institute, University of Berlin, of which he was Director, was completely destroyed. He is now at the Observatory at Fürstenfeldbruck, near Munich, engaged in geomagnetic research.

Merrill Bernard of the United States Weather Bureau has gone to Russia as Meteorological Attaché to the American Embassy. He expects to return to the United States in January.

Lyman J. Briggs, Director of the United States National Bureau of Standards since 1933, retired on October 31, 1945. Dr. Briggs became affiliated with the Bureau in 1917 and was made Chief of the Division of Mechanics and Sound in 1920, which post he occupied until he was appointed Director in 1933. Prior to beginning work with the Bureau, he was a physicist, successively with the Bureau of Soils and the Bureau of Plant Industry, both in the United States Department of Agriculture. Dr. Briggs was born in Assyria, Michigan, May 7, 1874. He received his baccalaureate degree from Michigan State College, his doctorate from Johns Hopkins University, and honorary degrees from six universities, including his alma mater. He is a member of the National Academy of Sciences, the National Advisory Committee for Aeronautics, and the National Conference on Weights and Measures. He has been a member of the American Geophysical Union since 1920. His successor as Director of the Bureau of Standards is Edward U. Condon, until recently of the Westinghouse Research Laboratories.

Detlev W. Bronk, Director of the Johnson Research Foundation for Medical Physics, University of Pennsylvania, has been named Foreign Secretary of the National Academy of Sciences and Chairman of the Division of Foreign Relations of the National Research Council, to fill the unexpired term of the late Walter B. Cannon. In the position of Chairman of the Division of Foreign Relations, Dr. Bronk becomes an ex-officio member of the Executive Committee of the American Geophysical Union.

D. C. Cox has resigned from the United States Geological Survey to accept a position as geologist for the Hawaiian Sugar Planters Experiment Station, Honolulu. He has been engaged in fluorite investigations in Colorado for the last two years.

Stephen Winchester Dana has been appointed Associate Professor of Geology at the University of Redlands, California, and entered upon his new duties in November. Prior to this work, he had been engaged in geophysical work for the Standard Oil Company of California in the Pacific Northwest. Plans are being laid at the University of Redlands to introduce courses in general geophysics.

Garrett B. Drummond has accepted appointment as an Assistant State Engineer of New Mexico, specializing in dams and reservoirs. He was formerly Associate Professor of Civil Engineering, University of New Mexico.

John A. Fleming, Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, and since 1925 the General Secretary of the American Geophysical Union, has been awarded the Charles Chree Medal and Prize for his outstanding contributions to geomagnetism. The presentation was made at the meeting of the Physical Society of London, by David Brunt, President of the Society, on December 6, 1945. Following the presentation, Dr. Fleming gave an address entitled "Geomagnetic secular variations and surveys." The Charles Chree Medal and Prize were founded by Jessie Chree in memory of her distinguished brother, who from 1893 to 1925 was superintendent of the magnetic and meteorological observatory at Kew, and who enjoyed a world-wide reputation for his researches in Terrestrial Magnetism. The Physical Society, of which he had been President, administers the generous benefaction.

Clement L. Garner of the United States Coast and Geodetic Survey retired October 1, after 38 years of service. After his graduation from North Carolina State College in 1907, he entered the Survey, where his early assignments were on vessels and with shore parties engaged in wire drag, hydrographic, topographic, and triangulation surveys in the United States, Alaska, Hawaii, and the Philippine Islands. One of his most interesting assignments was the measurement of a base in California which was used by the late A. A. Michelson in the determination of the velocity of light. From 1929 to 1936 he was Assistant Chief of the Division of Geodesy, becoming Chief of the Division of Geodesy on January 1, 1937. In 1940 he received the degree of Doctor of Engineering from North Carolina State College. He has held office in many scientific and engineering societies: President of the Washington Society of Engineers (1945), President of the Washington Academy of Sciences (1944), Director of the Society of American Military Engineers (since 1943), and Chairman of the Section of Geodesy, American Geophysical Union (1935-1938). He was Chairman of the Committee on Entertainment for the meeting of the International Union of Geodesy and Geophysics held in Washington in 1939. He is also a member of many other organizations affiliated with scientific and engineering endeavor.

Transactions, American Geophysical Union Volume 26, Number III December 1945

REPORT OF COMMITTEE ON DYNAMICS OF STREAMS

Lorenz G. Straub, Chairman

I shall report only very briefly on the activities of the Committee on Dynamics of Streams. The work of this group has been identified of late primarily by the accomplishments of a few individuals on special studies of stream-dynamics rather than by group accomplishment, which has been seriously handicapped by emergency conditions of the times. If I might use the vernacular, some members have at least temporarily gone completely out of circulation by the war--the chairman was out of the country a major part of the past year--but activity and group collaboration is now definitely coming back to the normal of previous years.

Two subcommittees have been operating within the Committee on Dynamics of Streams; one on Terminology of Sedimentation under the chairmanship of E. W. LANE, and one on Land Forms under IRVING B. CROSBY. It is proposed to establish other project-subcommittees to be concerned with specific problems related to the general field of the dynamics of streams. Such subgroups will not be continued indefinitely, but will rather be automatically dissolved when the specific study has been concluded.

The general field involving the forces which water exerts, the work done in eroding, transporting, and deposition of materials comprising the channel, both from a theoretical and experimental point of view, continues to attract the primary interest of the committee.

The Subcommittee on Sediment Terminology has prepared a glossary of terms and definitions of sediment with particular reference to its place in the general field of the dynamics of streams, and with the thought of making it as widely acceptable as possible to geologists and other scientists involved in problems of sediments.

This glossary has been distributed to qualified persons in the various fields of study of sedimentation, and the chairman of the subcommitteee is compiling and summarizing comments for a report which will be circulated further to a selected list of persons. In this way it is hoped to arrive at an acceptable terminology in sedimentation, and one on which considerable thought has been focused before its publication.

The Subcommittee on Land Forms has concerned itself with stream-meanders and entrenched meanders. A focal point of research in stream-meanders has been the United States Waterways Experiment Station under the general supervision of GERARD H. MATTHES, Director of the station, and a member of this Committee.

64th Floor,
350 Fifth Avenue,
New York, New York

(Manuscript received June 6, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until May 1, 1946.)

APPENDIX A--REPORT OF SUBCOMMITTEE ON LAND FORMS OF THE COMMITTEE ON DYNAMICS OF STREAMS

Irving B. Crosby, Chairman

The members of the Subcommittee on Land Forms of the Committee on Dynamics of Streams have been involved in war-activities and have therefore been unable to give much attention to the problems of the Committee. Fortunately, however, the laboratory investigation of meandering streams, described in our Report of 1943 (see p. 408, Transactions of 1943) and undertaken at the United States Waterways Experiment Station, Vicksburg, Mississippi, under the supervision of GERARD H. MATTHES, Director of the Experiment Station and member of this Subcommittee, was continued and has recently been brought to a close. A report thereon is in preparation for publication. MATTHES states:

> "Although an investigation of this kind is concerned with so many variables, and combinations of these variables, as to offer an almost inexhaustible field for further study, it was felt by MAX C. TYLER, President, Mississippi River Commission, who initiated and personally directed the tests, that sufficient information had now been gained to settle certain controversies relating to the fundamentals of river meandering as affecting problems of the lower Mississippi River. Also, that dissemination of the finds might result in eliciting further helpful information from engineers and geologists engaged in similar studies.
>
> "The tests were made under many different conditions, using a variety of granular materials which were given varying degrees of cohesiveness. This latter aspect demanded considerable study, as it was necessary not only to overcome the commonest obstacle met with in laboratory streams, namely excessive erodibility of the banks, but also to simulate the different degrees of erodibility which occur in the banks of natural streams, more particularly of the lower Mississippi River.
>
> "Perhaps the most interesting part of the investigation involved the reproduction to scale of long stretches of the lower Mississippi River in order to determine the probable effects of stabilizing the caving banks by means of various types of works.
>
> "The investigation was conducted by JOSEPH F. FRIEDKIN, Corps of Engineers, United States Army, attached to the Waterways Experiment Station."

It is hoped that when this report is available for study, it will be possible to apply the conclusions to other rivers besides the lower Mississippi, and to formulate principles for the different types of streams.

In the Report of 1943 reference was made to the study of entrenched meanders which was also being carried on. It has not been possible to extend this study on account of the pressure of war-activities, but the problem is one which merits thorough study and in which it is believed good progress can be made when conditions again permit the members to give their attention to research.

6 Beacon Street,
Boston, Massachusetts

(Manuscript received June 6, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until May 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 455, 456, 459, 460, and 462)

PERSONALIA

Gail A. Hathaway of the Office of the Chief of Engineers, War Department, has been decorated with the Bronze Star for organizing and directing hydrometeorological studies essential to the crossing of the Rhine. The award was made by direct authorization of President Truman.

C. B. Hunt, who has been serving as Staff Geologist of the United States Geological Survey, has been designated Regional Geologist of the Survey with headquarters at Salt Lake City. The Salt Lake Region includes Utah and Arizona.

Ralph B. Kennard, who is in France teaching Physics at the Biarritz American University, has been selected by the Ninth Air Force to lecture their men in Germany on the atomic bomb. Dr. Kennard is on leave from the National Bureau of Standards.

M. R. Klepper recently returned from Brazil, where he has been studying the mica deposits for the United States Geological Survey and the Brazilian government.

Conrad B. Krauskopf of the United States Geological Survey has gone to Mexico for four months to study various phases of Parícutin under the auspices of the Survey and the Interdepartmental Committee for Cooperation with the American Republics, United States Department of State.

H. S. Ladd has been appointed Chief of the Division of Areal Geology and Basic Sciences of the United States Geological Survey. The Military Geology Unit and Section of Engineering Geology have been transferred to this Division.

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REPORT OF THE COMMITTEE ON LAKES, 1944-1945

S. T. HARDING, Chairman

Thomas C. Adams **C. S. Howard** **Adolph F. Meyer**
Phil E. Church **Ralf R. Woolley**

The membership of the Committee on Lakes continued without change during the year. Group action by the Committee has not been undertaken because of the War. Each member has continued such work in this field as his other activities have permitted.

PHIL E. CHURCH has continued his work on the results of observations on Lake Michigan. His second paper on the "Annual temperature cycle of Lake Michigan, II: Spring warming and summer stationary period, 1942," has been completed and is at present in press. It will be published as Miscellaneous Report 18 of the Department of Meteorology, University of Chicago. The paper consists of a discussion of the warming phase of a deep, fresh-water lake. One more report on this lake is being written; it will discuss autumnal cooling and the change of heat-content of the lake for the year 1941-42.

RALF R. WOOLLEY was the author of a paper on Great Salt Lake, which was published in the August, 1944, issue of Civil Engineering [v. 14, No. 8]. He is now preparing a bibliography on Great Salt Lake covering the early reports, zoology, botany, chemistry, hydrology, and other features of the Lake. [This has been received and will be published in a forthcoming issue of the Transactions--Editor]

C. S. HOWARD reports continuation of the collection of samples in Lake Mead by the various interests there. He calls attention to Miscellaneous Publication 491 of the United States Department of Agriculture entitled "Stratified flow in reservoirs and its use in prevention of silting," by HUGH STEVENS BELL. Although dated September, 1942, this publication may not have been received by many until within the past year.

The Committee has not planned any specific program for the coming year. The continuation of a Committee on Lakes is recommended so that its organization may be maintained and available when conditions may permit the resumption of activity in its field.

(Report received May 9, 1945; presented at the Twenty-Sixth
Annual Meeting, Washington, D. C., May 31, 1945.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 455, 456, 458, 460, and 462)

PERSONALIA

Chester R. Longwell, Chairman of the Department of Geology at Yale University, has been on tour giving a series of lectures under the auspices of the Distinguished Lecture Series of the American Association of Petroleum Geologists. His subject was "Geology of the Basin Ranges--revelations and problems."

Gerard H. Matthes, Director of the United States Waterways Experiment Station at Vicksburg, Mississippi, for the past four years retired on September 30, 1945. Mr. Matthes went to Vicksburg in 1932 as Consultant to the President of the Mississippi River Commission. He was born in Amsterdam, Holland, in 1874, received his baccalaureate degree from Massachusetts Institute of Technology in 1895, and since that time has held numerous important posts in hydraulic engineering and aerial survey work.

I. F. McAllister of the United States Geological Survey has gone to Chile to accompany a Chilean Government expedition which will make a geological reconnaissance of the coast southward from the 42nd parallel.

REPORT OF COMMITTEE ON THE CHEMISTRY OF NATURAL WATERS, 1944-1945

C. S. Howard, Chairman

The membership of the Committee during the past year was as follows:

Stanley W. Lohman, U. S. Geological Survey, Denver, Colorado
S. Kenneth Love, U. S. Geological Survey, Washington, D. C.
M. R. Miller, Agricultural Experiment Station, Reno, Nevada
Melvin Romanoff, National Bureau of Standards, Washington, D. C.
C. S. Scofield, Department of Agriculture, Beltsville, Maryland
T. G. Thompson, University of Washington, Seattle, Washington
C. S. Howard, U. S. Geological Survey, Albuquerque, New Mexico

So much of the attention of members of the Committee has been given to war work that it has not been possible to compile a comprehensive statement of current research work on the chemistry of natural waters. Most of the agencies that have previously reported have curtailed their research activities to little more than continuation in a small and somewhat routine fashion of long-time projects on which progress reports have been made previously.

United States Geological Survey,
Albuquerque, New Mexico

(Manuscript received July 23, 1945; presented at the Twenty-Sixth Annual Meeting, Washington, D. C., May 31, 1945; open for discussion until May 1, 1946.)

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 455, 456, 458, 459, and 462)

PERSONALIA

P. L. Mercanton has retired from the directorship of the Swiss Meteorological Service and now has the title of Honorary Professor and is residing at Lausanne, Switzerland. Professor Mercanton is Vice-President of the Association of Seismology and a member of the Commission on Snow and Glaciers of the Association of Scientific Hydrology, International Union of Geodesy and Geophysics.

S. Spencer Nye has gone to northern Chile to investigate ground-water problems. The field work is expected to last about eight months.

Elburt F. Osborn, who has been engaged in research in silicate chemistry with the Geophysical Laboratory of the Carnegie Institution of Washington since 1938, has accepted a positiion on research work on optical glass with the Eastman Kodak Company at Rochester, New York.

J. Clement Owen has returned from military leave to his duties in the United States Soil Conservation Service.

William C. Putnam has accepted an Associate Professorship in Geology at the University of California in Los Angeles. He was formerly with the United States Geological Survey.

H. L. Rasé, Jr. is now Geophysicist on Party No. 8 of the Gulf Research and Development Company. The party is now working in Mississippi. He was formerly in the Geophysics Department of the Laboratory of the Gulf Research and Development Company in Harmonville, Pennsylvania.

C. W. Thornthwaite of the United States Soil Conservation Service, has recently returned to Washington from Mexico, where he was on special duty with the Mexican Government. He worked with technicians in the Secretaria de Agricultura y Fomento on climatic problems, and in collaboration with hydrologists in the Comisión Nacional de Irrigación made a provisional map showing the needs for supplementary water for irrigation in the Republic. He worked closely with two Mexican members of the Union, Alfonso Contreras Arias and Andres Garcia Quintero.

LETTERS TO EDITOR

LABORATORY OF THEORETICAL GEOTECTONICS

I have the pleasure to inform you that a Laboratory of Theoretical Geotectonics was recently organized in the Institute of Theoretical Geophysics of the Academy of Sciences of the U. S. S. R. The Laboratory works on the problems of mechanics of folding, of development of epeirogenic movements and of interrelation between geophysical and geotectonic phenomena. We should be happy to exchange information with your Section and to cooperate with our colleagues in the New World.

I hope we soon shall be able to send you some of our reports.

V. V. BELOUSSOV,
Chief of the Laboratory of Theoretical Geotectonics,
Institute of Theoretical Geophysics, Academy of
Sciences of the U. S. S. R.

48, Piatnitzkaia,
Moscow, U. S. S. R.

(Received October 25, 1945)

PUBLICATIONS NEEDED FOR LIBRARY OF HYDROGRAPHIC OFFICE

During the war an extensive program in oceanography was developed here in the Hydrographic Office. In this work we were continually hampered by a lack of adequate library facilities. As a result we propose to build up a working library in oceanography to meet our future needs and those of the Navy Department as a whole.

It has occurred to me that Members of the American Geophysical Union may have publications pertaining to physical oceanography which they no longer need. These may be reprints of their own papers, duplicate copies of various periodicals, books, etc. Any contribution of this sort which a member cares to donate will be greatly appreciated and will be widely used. Please send contributions to: Hydrographic Office Library, Navy Department, Washington 25, D. C.

G. S. BRYAN,
Rear Admiral, U. S. N.(ret.)
Hydrographer.

Hydrographic Office,
Navy Department,
Washington, D. C.

(Received November 2, 1945.)

THE DANISH METEOROLOGICAL INSTITUTE AND ITS OBSERVATORIES DURING THE WAR

With great pleasure we--thanks to the liberation of our country by the Allied Forces--are able to send you this letter containing certain information which may be of interest for you and possibly to some extent to the readers of the Transactions. In these years of war several magnetic observatories have been distrubed or destroyed, but our Rude Skov and Godhavn observatories are safe.

The Rude Skov Observatory has been undistrubed during the whole war and magnetic registrations of all kinds have been continued. Magnetic character-numbers have been determined and mailed to January 1, 1945. Part I of the Magnetic Yearbook for 1943 was published in December, 1944. The examination and improvement of the la Cour variometers have also been continued; A. Groot Hansen, former assistant of the Observatory, and J. Egedal have constructed a new la Cour Z-balance able to keep a fairly constant zero-point value during daily variations of the temperature.

Since communication with Greenland was interrupted on April 9, 1940, the Greenland office of the Meteorological Institute of Copenhagen has continued the publication of the Yearbooks of the Magnetic Observatory at Godhavn (Greenland). Thus since 1940 the "Annuaire magnétique II le Groenland" for 1934, 1935, 1936, 1937, 1938, 1926-27, and 1928 have all been printed. The Yearbook for 1929 is in press but the Yearbooks for 1930 and 1931 have not yet been published. Besides these the magnetic results from Julianehaab for the period from September, 1932, to August, 1934, have been published under the title "Observations magnétiques a Julianehaab 1932-1934" by

LETTERS TO EDITOR (Concluded)

Johannes Olsen and Knud Thiesen. Viggo Laursen has published "Observations faites à Thule 1932-33: Première partie, magnétisme terrestre."

The manufacture of magnetic instruments after the design of D. la Cour has been continued and new instruments are still available upon application to the Danish Meteorological Institute. BMZ's have been used for field-work in Denmark, Sweden, Finland, Latvia, Holland, and Switzerland. In several cases the constants have been redetermined in Copenhagen at intervals. The results have been fairly good. Four instruments belonging to the Government of Greenland have been investigated here during the war, and the constancy has turned out to be satisfactory. For BMZ 17, BMZ 18, BMZ 19, and BMZ 20 the constants have decreased by 31γ, 30γ, 15γ, and 2γ, respectively, in the course of three years.

The study of QHM and BMZ has been continued by regular observations of the constants of several QHM's and BMZ's and some of the results have been published in "Communications magnétiques" at Copenhagen in 1942: No. 19 on "The magnetometric zero balance: The BMZ," by D. la Cour; and No. 20 on "Some investigations on the constancy of the QHM magnetometer," by Johannes Olsen.

JOHANNES OLSEN
J. EGEDAL

Det Danske Meteorologiske Institut,
Copenhagen, May 18, 1945.

NOTES AND PERSONALIA

(See also pp. 351, 387, 388, 390, 429, 430, 440, 444, 455, 456, 458, 459, and 460)

PERSONALIA

Louis B. Slichter has been appointed Professor of Geophysics at the University of Wisconsin. Until recently he was Professor of Geophysics at the Massachusetts Institute of Technology.

H. U. Sverdrup, Director of the Scripps Institution of Oceanography, visited England and Norway during the summer and reports that in Great Britain there are plans for extensive oceanographic work, and that they are anxious to establish the closest possible cooperation with the United States in this connection. In Norway he found that plans are underway for the holding of a General Assembly of the International Union of Geodesy and Geophysics in Norway, either in the summer of 1946 or of 1947. At the time of the Seventh Triennial Assembly in Washington in 1939 it was planned that the Eighth Triennial Assembly was to be held in Bergen, Norway, in 1942.

Thomas G. Thompson, on military leave from the University of Washington, is Technical Director of the project of the Chemical Warfare Service on San Jose Island in the Bay of Panama. He expects to return to reserve status soon and resume his oceanographic work on the West Coast.

F. A. Vening Meinesz, Director of the Meteorologic-Oceanic-Geophysic Institute at De Bilt, The Netherlands, has recently arrived in the United States. He will spend about three months in this country renewing scientific contacts which were completely severed during the period of the Occupation.

A. E. Weissenborn, who has been Acting Regional Geologist of the United States Geological Survey at Rolla, Missouri, has been designated Regional Geologist of the Survey with headquarters at Spokane, Washington; the Spokane region will include Washington, Oregon, Idaho, and Montana. The Rolla office will be closed.

Gordon R. Williams has been transferred to the Providence, Rhode Island, District Office of the Corps of Engineers, where he will have charge of hydraulic design, hydrologic studies, and the preparation of flood control reports in the Connecticut River basin. He has recently been working on flood control and related problems in the Civil Works Division of the Office of the Chief of Engineers in Washington, D. C.

Walter T. Wilson has recently taken up duties in the Office of the United States Weather Bureau in San Francisco, in connection with the cooperative research program on snow being undertaken by the Weather Bureau and the Corps of Engineers. He was formerly connected with the Hydrometeorological Section of the Weather Bureau in Washington, D. C.

Warren E. Wilson has opened an office as consulting engineer in Winnetka, Illinois. He was formerly Chairman of Fluid Mechanics and Thermodynamics at the Armour Research Foundation.

Transactions, American Geophysical Union Volume 26, Number III December 1945

UNION, SECTION, AND COMMITTEE ACTIVITIES

UNION ACTIVITIES

EDUCATION IN GEOPHYSICS

Geophysics is that field of science which deals with the natural phenomena of the Earth and the application of the laws of physics to interpretation and application of those phenomena and their interrelationships to scientific and economic progress. It is only in recent years that our colleges and universities have recognized the need of systematized instruction in Geophysics as an entity for the award of bachelor, master, and doctorate degrees rather than as incidental to an associated field, for example, Engineering, Physics, or Geology. The need of enlarged understanding of the interior and exterior of our Earth for human welfare is being met by a pronounced trend toward more comprehensive education in Geophysics as a profession.

Man still has a long way to go before his knowledge of the Earth is sufficient to meet his increasing needs. This was demonstrated in various branches of Geophysics in the emergency of World War II. Our knowledge of the interior of the Earth, through direct observation at widely scattered points, extends only to about three miles of the 4000 miles to the Earth's center and that of the bed of the ocean is very limited. It is likely, therefore, that the need for natural resources--now being rapidly depleted on land-areas--will drive us to greater depths and to ocean-areas. It is largely the responsibility of the Geophysicist to see that ample potential reserves of essential resources are continually in prospect.

Developments during the War in the field of Geomagnetism, for example, radio-communication disturbances, radar, the odograph, isomagnetic maps, improved instrumentation for areal magnetic surveys, point to their great future peacetime value. In its development of water-resources and control of erosion and floods, Hydrology will solve many increasingly complex problems. These are examples only to indicate that continuing progress in Geophysics, embracing the whole Earth, will contribute much to the advancement of our civilization and international good-will.

In the spring of 1945 the American Geophysical Union, long interested in forwarding of education in Geophysics, distributed to all colleges and universities offering instruction in science, a questionnaire asking for information bearing on established and postwar courses relating to its fields. This was more particularly in response to a request of the National Roster of the War Manpower Commission to supply information to men returning from the military services. The replies to this questionnaire are summarized in Table 1. Although one Canadian school is listed, no attempt was made to canvas a complete list of Canadian schools. Specific information was requested under nine branches as follows:

GEODESY: Geodetic surveying; size and shape of the Earth; astronomy; determination latitude and longitude; navigation; latitude variation; photogrammetry; gravimetric surveys; and other related work.

SEISMOLOGY: Earthquake study; crustal and interior structure of the Earth; earthquakes in reference to the design of buildings; seismic prospecting; and other related work.

METEOROLOGY: Dynamic meteorology; synoptic meteorology; long-range forecasting; climatology; and other related work.

TERRESTRIAL MAGNETISM AND ELECTRICITY: Theory of electricity and magnetism; the magnetic field of the Earth; magnetic surveys; Earth-currents and atmospheric electricity; applications of magnetic and electrical theory; relations to cosmic and solar phenomena and wireless and wired communications; and other related work.

OCEANOGRAPHY: Waves, tides, currents, and related phenomena; configuration and nature of ocean beds; physical and chemical properties of sea water; marine biology; and other related work.

VOLCANOLOGY: Origin of igneous rocks and ore deposits; extrusive and intrusive activity; petrology; and other related work.

(Text continued on page 476)

Table 1--Educational institutions, listed according to States

Key to symbols:

a--Aeronautical Engineering
b--Agricultural Engineering
c--Agronomy
d--Anthropology
e--Astronomy
f--Biology
g--Graduate courses
h--Chemistry
i--Civil Engineering
j--Earth Sciences
k--Electrical Engineering
l--Geography
m--Geological Engineering
n--Geology
o--Geophysics
p--Grad. School, Engineering
q--Hydraulics
r--Irrigation
s--Mathematics
t--Mechanical Engineering
u--Undergraduate courses

College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	P	u	g	P	u	g	P	u	g	P
ALABAMA												
Alabama Polytechnic Institute												
Auburn	+	..	i	..	..	..	+	..	a	+	..	F
University of Alabama			a						a			
Tuscaloosa	+	..	F	+	..	F	+	..	F	..	..	..
ARIZONA												
College of Mines, University of												
Arizona, Tucson	..	..	..	..	..	..	+	..	F	..	..	..
CALIFORNIA												
California Institute of Technology						n						
Pasadena	+	+	n	+	+	t	+	+	x	..	+	n
San Diego State College												
San Diego	+	..	n	+	..	n	+	..	n	+	..	F
University of California			ni									Fk
Berkeley	+	..	e	+	+	n	+	+	l	+	..	i
University of California									xl			
Los Angeles and La Jolla	+	..	e	+	+	n	+	+	C	+	+	F
Davis	..	..	..	..	..	..	..	..	..	..	..	..
University of Southern California												
Los Angeles	Some work in various geophysical fields offered in As-											
COLORADO												
Colorado A. and M. College												
Fort Collins	+	..	i	..	..	..	+	..	i	..	..	..
Colorado School of Mines												
Golden	+	+	o	+	+	o	..	..	..	+	+	o
University of Colorado									n			
Boulder	..	..	..	..	..	..	+	+	l	..	..	..
CONNECTICUT												
U. S. Coast Guard Academy												B
New London	+	..	B	+	..	B	+	..	H	+	..	H
DISTRICT OF COLUMBIA												
Catholic University of America												
Washington	+	..	i	..	..	..	..	..	..	+	..	F
Howard University												
Washington	+	..	i	..	..	..	..	..	..	..	..	..
FLORIDA												
University of Florida			il						F			
Gainesville	+	..	e	+	..	n	+	..	l	+	..	F
GEORGIA												
University of Georgia												
Athens	..	..	..	..	..	..	+	..	l	..	..	..
HAWAII												
University of Hawaii												
Honolulu	..	..	..	..	..	..	+	..	l	..	..	..
ILLINOIS												
Northwestern University			e						n			
Evanston	+	+	s	..	..	..	+	..	l	+	..	F
Parks Air College												
East St. Louis	..	..	..	..	..	..	+	..	x	..	..	..
University of Illinois												
Urbana	+	..	i	..	..	..	..	..	..	..	..	..

v--Mechanics
w--Mechanics and Hydraulics
x--Meteorology
y--Mineralogy
z--Mining
A--Naval Science
B--Navigation
C--Oceanography
D--Petroleum Engineering
E--Photogrammetry
F--Physics
P--Department in which courses are offered
T./M. and E.--Terrestrial Magnetism and Electricity
Geophys. Prosp.--Geophysical Prospecting
G--Sanitary Engineering
H--Seamanship
I--Soils
J--Zoology

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	..	..	..	+	..	i	..	..	..	..	..	..
..	..	..	+	+	n	+	+	i n	..	+	n	+	..	z n
+	..	n	+	..	n	..	..	..	+	..	n	..	..	..
+	+	n	+	+	n	+	+	i	+	+	n	+	+	n
+	..	n	+	..	n	..	..	..	+	..	n	..	..	..
..	..	..	+	..	n	+	..	r	..	+	n	+	+	n
+	+	C	+	+	n	..	..	..	+	+	n	+	+	n
..	..	..	..	..	..	+	+	r	..	..	..	..	..	..

tronomy, Civil Engineering, Geology, and Physics

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	+	+	o
..	..	..	+	+	n	..	..	..	+	..	n	+	..	n
+	..	B H	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
+	..	n f	+	..	n	+	+	i	..	..	..	..	..	..
+	..	l	..	..	..	+	..	n	+	..	n	..	..	..
..	..	..	+	..	l	..	..	..	..	..	..	..	..	..
..	..	..	+	+	n	+	..	n l i	+	..	n	..	..	..
+	..	x	..	..	..	..	..	..	..	..	..	..	..	..
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Key to symbols:

a--Aeronautical Engineering
b--Agricultural Engineering
c--Agronomy
d--Anthropology
e--Astronomy
f--Biology
g--Graduate courses
h--Chemistry
i--Civil Engineering
j--Earth Sciences
k--Electrical Engineering
l--Geography
m--Geological Engineering
n--Geology
o--Geophysics
p--Grad. School, Engineering
q--Hydraulics
r--Irrigation
s--Mathematics
t--Mechanical Engineering
u--Undergraduate courses

College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	p	u	g	p	u	g	p	u	g	p
INDIANA												
Earlham College **Earlham**	+	..	s	..	..	..	+	..	n- l	..	..	..
Indiana University **Bloomington**	..	..	..	..	..	..	+	..	n- l	..	..	..
Purdue University **Lafayette**	+	..	i	..	..	..	..	..	..	..	..	..
IOWA												
Iowa State College **Ames**	..	..	..	..	..	..	+	+	F	..	+	F
Drake University **Des Moines**	..	..	..	..	..	..	+	+	l- n	..	..	..
State University of Iowa **Iowa City**	..	..	..	..	+	n	+	..	t n F	+	..	F
KANSAS												
Kansas State College **Manhattan**	+	+	i	+	+	n	+	+	F	+	+	k F
University of Kansas **Lawrence**	A general curriculum in Geophysics is provided through											
University of Wichita **Wichita**	..	..	..	..	..	..	+	..	F	+	..	F
KENTUCKY												
University of Kentucky **Lexington**	+	..	i	..	..	..	+	..	n	+	..	F
LOUISIANA												
Louisiana State University **Baton Rouge**	+	..	i	..	..	..	+	..	F	+	..	F
Southwestern Louisiana Institute **Lafayette**	+	..	i	+	..	n	..	..	..	+	..	n k
Tulane University **New Orleans**	+	..	e	+	..	n	+	..	e	+	..	F k
MAINE												
University of Maine **Orono**	..	..	..	..	..	..	+	..	F	..	..	..
MARYLAND												
Johns Hopkins University **Baltimore**	+	..	n	+	..	n	..	..	..	..	..	..
MASSACHUSETTS												
Clark University **Worcester**	+	+	F ls	..	..	..	+	+	l	+	..	F
Harvard University **Cambridge**	+	..	e n	+	+	n	+	+	n	+	+	n F
Massachusetts Institute of Technology, Cambridge	+	+	i	..	+	i	+	+	x	..	..	..
Northeastern University **Boston**	Undergraduate work in Geodesy, Oceanography, and Hy-											
Tufts College **Medford**	+	..	A i	..	..	..	+	..	F	..	..	..
Worcester Polytechnic Institute **Worcester**	+	..	i	..	..	..	..	..	..	..	..	..

v--Mechanics
w--Mechanics and Hydraulics
x--Meteorology
y--Mineralogy
z--Mining
A--Naval Science
B--Navigation

C--Oceanography
D--Petroleum Engineering
E--Photogrammetry
F--Physics
P--Department in which courses are offered
T. M. and E.--Terrestrial Magnetism and Electricity
Geophys. Prosp.--Geophysical Prospecting

G--Sanitary Engineering
H--Seamanship
I--Soils
J--Zoology

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	+	..	n-l	+	..	n-l	..	..	..	..	..	..
+	..	n-l	+	+	n-l	+	..	n-l	+	+	n-l	+	..	n-l
..	..	..	..	..	..	+	..	i	..	..	..	..	..	..
..	+	n	+	+	n	+	..	i	..	..	..	+	..	n
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
+	..	n	+	+	n	+	+	n	+	+	w n	..	..	..
+	+	n	+	+	n	+	+	i n	+	+	n	+	+	F

science courses and special courses in the several departments of the University.

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	+	+	n	+	..	i	..	+	n	..	..	..
+	..	J	+	+	n	+	..	q	+	..	n	+	..	n
..	..	..	+	..	n	..	..	..	..	..	..	..	..	..
+	..	n	+	..	n	+	..	n	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
+	..	n	+	..	n	+	..	n	+	+	n	+	..	n
..	..	..	+	..	n	+	..	l	+	+	l	..	..	..
+	+	f n	+	+	n	+	+	n p	+	+	n	+	+	n
+	..	x	+	+	n	+	+	i	+	+	n	+	+	n

drology offered in various courses in Engineering.

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	+	..	n	+	..	i	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

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College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	P	u	g	P	u	g	P	u	g	P
MICHIGAN												
Michigan College of Mining and Technology, Houghton	+	..	i	..	..	..	+	..	l F	..	..	..
Michigan State College East Lansing	..	..	..	..	..	..	..	..	..	..	..	..
University of Detroit Detroit	+	..	i	..	..	..	+	..	a	..	..	..
University of Michigan Ann Arbor	+	..	i	+	+	n	+	+	n	..	+	F
Wayne University Detroit	..	..	..	..	..	..	+	..	l- n	+	..	l- n
MINNESOTA												
University of Minnesota Minneapolis	+	..	e i	+	+	n	+	..	F	+	+	F k
MISSISSIPPI												
Mississippi State College State College	..	..	..	..	..	..	+	..	F a	..	..	..
MISSOURI												
Institute of Geophysical Technology, St. Louis University, St. Louis	..	..	..	+	+	o	+	+	o	+	+	o
Missouri School of Mines Rolla	+	..	i	+	..	n	..	..	..	+	..	F
University of Missouri Columbia	..	..	..	..	..	..	+	..	n- l	..	..	..
MONTANA												
Montana State College Bozeman	Plan to offer work in Geodesy, Seismology, Meteorology, ·											
Montana School of Mines, Butte	Subject matter in these fields is taught in various courses,											
NEBRASKA												
University of Nebraska Lincoln	+	+	s i	..	..	..	+	+	l	+	+	F
NEW HAMPSHIRE												
Dartmouth College Hanover	+	..	?	..	..	..	+	..	?	..	..	..
University of New Hampshire Durham	..	..	..	..	..	..	+	..	n	..	..	..
NEW JERSEY												
Newark College of Engineering Newark	+	+	i	+	..	i	+	..	i	+	..	F
Princeton University Princeton	+	+	si em	+	..	sF mn	+	..	sF ea	+	+	sF mk
Rutgers University New Brunswick	+	..	i e	..	..	..	+	..	F x	+	..	F
NEW MEXICO												
New Mexico School of Mines Socorro	+	..	n i	+	..	n	..	..	..	+	..	F
University of New Mexico Albuquerque	..	..	..	..	..	..	+	..	F d	..	..	..

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Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	..	..	..	..	..	..	..	..	..	+	+	F
..	..	..	..	..	..	..	..	..	..	..	..	+	..	F' e
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	+	+	n y	+	+	n i	+	+	n	+	..	n
+	..	l- n	+	..	l- n	+	..	l- n	+	..	l- n	..	..	..
..	..	..	+	..	n	+	+	i n	+	..	n	+	+	?
..	..	..	..	..	..	..	..	..	..	..	..	+	..	F
..	..	..	+	+	o	+	+	o	..	..	..	+	+	o
..	..	..	+	+	n	..	+	n	+	+	n	+	..	n
..	..	..	+	+	n- l	..	+	n- l	..	+	n- l	..	..	..

Tectonophysics, and Geophysical Prospecting in the postwar period.

chiefly in the departments of Geology and Physics.

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
..	..	..	+	+	n	+	+	i	..	..	..	..	..	..
+	..	?	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	+	+	n	..	..	..	..	..	..	..	..	..
+	..	i	+	..	i	+	..	i	..	..	..	..	..	..
..	..	..	+	+	sFh nm	+	+	sFh inm	+	+	sFhn eia	+	+	sFh nim
..	..	..	..	..	..	+	..	GI	..	..	..	..	..	..
..	..	..	+	..	n	+	..	i	..	..	..	..	..	..
+	..	n	+	..	n	+	..	n i	..	..	..	..	..	..

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College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	P	u	g	P	u	g	P	u	g	P
NEW YORK												
Clarkson College of Technology												
Potsdam	+	..	i	+	..	i	+	..	i	+	..	k
Columbia University			ei									F
New York	+	+	n	..	+	n	+	..	n	+	+	n
Cornell University												
Ithaca	Some graduate courses offered involving geophysical fields,											
Fordham University												
New York	..	..	..	+	+	F	+	+	F	+	+	F
Manhattan College												
New York	+	..	i	+	..	i	+	..	i	..	..	..
New York University			F									x
New York	+	+	i	..	+	i	+	+	x	..	+	F
Rensselaer Polytechnic Institute												
Troy	+	+	i	+	..	n	+	..	a	+	+	F
Syracuse University			EF						l			
Syracuse	+	+	i	+	+	n	+	..	F	+	+	F
University of Buffalo												
Buffalo	..	..	..	+	..	n	+	..	n	+	+	F
University of Rochester												
Rochester	..	..	..	..	..	..	+	..	n	..	..	..
NORTH CAROLINA												
North Carolina State College												
Raleigh	..	..	..	..	..	..	+	+	F	+	+	F
NORTH DAKOTA												
North Dakota Agricultural			s			n			l			k
College, Fargo	+	..	i	+	..	F	+	..	F	+	..	F
University of North Dakota												
Grand Forks	+	..	i	..	..	..	+	..	l	+	..	F
OHIO												
Case School of Applied Science												
Cleveland	+	+	i	..	..	..	..	..	..	..	..	..
College of Wooster			n-			n-			n-			
Wooster	+	..	l	+	..	l	+	..	l	+	..	F
Kenyon College												
Gambier	..	..	..	..	..	..	+	..	F	..	..	..
Ohio State University									l			
Columbus	+	..	i	..	..	..	+	..	n	+	+	F
Ohio University			s						l-n			F
Athens	+	..	i	..	..	..	+	+	F	+	+	k
Ohio Wesleyan University												
Delaware	..	..	..	..	..	..	+	..	n	..	..	..
University of Cincinnati									n-l			
Cincinnati	..	..	..	..	..	..	+	..	F	..	..	..
Western Reserve University						n-			n-			
Cleveland	+	..	e	..	+	l	+	..	l	..	..	..
Xavier University												
Cincinnati	..	..	..	+	..	F	+	..	F	..	..	..

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u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	+	..	i	+	..	i	..	..	..	..	..	..
+	+	n J	..	+	n	+	+	i	..	+	n	..	+	n
but no specialties in Geophysics other than Meteorology.														
..	..	..	..	..	..	..	..	..	..	..	..	+	+	F
+	..	i	..	..	..	+	..	i	+	..	i	..	..	..
..	+	x F	..	..	..	..	+	x i	..	..	..	..	+	F
..	..	..	..	..	..	+	..	n	..	..	..	+	..	n
+	+	n	+	+	n	+	+	qn Fh	+	+	n	+	+	F n
..	..	..	+	..	n	+	..	n	+	..	n	..	..	..
+	..	n f	+	+	n	..	..	..	+	+	n	..	..	..
..	..	..	+	+	n	+	..	i	..	..	..	+	..	n
+	..	n y	+	..	n	+	..	i n	+	..	n F	+	..	n F
+	..	n	+	..	n	+	..	n	+	..	n	..	..	..
..	..	..	..	..	..	+	..	i	..	..	..	..	..	..
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College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	P	u	g	P	u	g	P	u	g	P
OKLAHOMA												
Oklahoma A. and M. College Stillwater	+	..	i	..	..	..	+	..	t	..	..	..
University of Oklahoma Norman	+	+	e F	+	+	F n	+	..	n l	+	..	F
University of Tulsa Tulsa	..	..	..	..	..	..	..	..	..	..	..	..
OREGON												
Oregon State College Corvallis	+	..	F	..	+	F	+	+	F	..	+	F
University of Oregon Eugene	+	..	s F	Plans under way			..	+	F	+	..	F
University of Portland Portland	+	..	F	..	..	..	+	..	F	+	..	F
PENNSYLVANIA												
Lafayette College Easton	..	..	..	..	..	..	+	..	n	..	..	..
Lehigh University Bethlehem	..	..	..	..	..	..	+	..	n	..	..	..
Pennsylvania State College State College	+	+	j	+	+	j	+	+	j	+	+	j
Temple University Philadelphia	+	..	F	..	..	..	+	..	F	+	+	F
University of Pennsylvania Philadelphia	..	..	..	+	..	j	..	..	.,	+	..	k
University of Pittsburgh Pittsburgh	+	..	ie s	+	+	F	+	..	xl F	+	+	F
SOUTH CAROLINA												
The Citadel Charleston	..	..	..	..	..	..	+	..	n	..	..	..
Clemson College Clemson	..	..	..	+	..	n	+	..	n	..	..	..
University of South Carolina Columbia	..	..	..	+	+	n	+	..	n	..	..	..
SOUTH DAKOTA												
South Dakota School of Mines Rapid City	+	..	i n	..	..	..	+	..	F	+	..	k
TENNESSEE												
Tennessee Polytechnic Institute Cookeville	..	..	..	..	..	..	+	..	F	..	..	..
University of Tennessee Knoxville	+	..	n- l	+	..	n- l	+	..	n- l	..	..	..
TEXAS												
A. and M. College of Texas College Station	..	..	..	Postwar plans			..	..	..	..	..	..
Rice Institute Houston	..	..	..	..	..	..	..	..	..	+	..	F
Southwestern University Georgetown	+	..	n	..	..	..	+	..	e	..	..	..
Texas Technological College Lubbock	Much of this work given as undergraduate work, largely in											
University of Texas Austin	..	..	..	..	..	..	+	..	?	..	..	..

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u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..	..	..	..	..	..	+	..	i	..	..	..	..	..	..
+	+	n	+	..	n	+	..	n	+	..	n	+	..	F
..	..	..	..	..	..	..	..	..	..	..	..	+	..	o
Postwar plans			..	+	n	+	+	in I	in various courses			..	+	n F
Postwar plans			+	+	n	..	..	..	+	..	n	..	..	..
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..	..	..	+	+	n	..	+	i	+	+	n	+	..	F n
..	..	..	+	+	j	+	+	bi j	+	+	j	+	+	j
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+	+	n f	+	+	n D	+	+	n	+	+	n	+	..	n F
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the department of Geology.												+	..	n
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Table 1--Educational institutions, listed according to States and

Key to symbols:

a--Aeronautical Engineering	h--Chemistry	o--Geophysics
b--Agricultural Engineering	i--Civil Engineering	p--Grad. School, Engineering
c--Agronomy	j--Earth Sciences	q--Hydraulics
d--Anthropology	k--Electrical Engineering	r--Irrigation
e--Astronomy	l--Geography	s--Mathematics
f--Biology	m--Geological Engineering	t--Mechanical Engineering
g--Graduate courses	n--Geology	u--Undergraduate courses

College or University, Address	Geodesy			Seismology			Meteorology			T. M. and E.		
	u	g	P	u	g	P	u	g	P	u	g	P
UTAH												
Brigham Young University Provo	..	..	..	..	..	..	+	+	F	..	..	..
University of Utah Salt Lake City	..	..	..	..	..	..	+	..	F	..	..	..
VIRGINIA												
University of Virginia Charlottesville	+	..	e	..	..	..	..	..	..	+	+	F
Virginia Military Institute Lexington	+	..	i	..	..	..	..	..	..	+	..	F
Virginia Polytechnic Institute Blacksburg	+	..	i	..	..	..	+	..	F	+	..	F
Virginia State College for Negroes Petersburg	..	..	..	..	..	..	..	..	..	+	..	F
WASHINGTON												
State College of Washington Pullman	..	..	..	..	..	..	..	..	..	..	..	..
University of Washington Seattle,	+	..	e	+	..	n	+	+	l	..	..	..
WEST VIRGINIA												
Marshall College Huntington	..	..	..	+	..	n	+	..	n-l	+	..	F
West Virginia University Morgantown	..	..	..	..	..	..	+	..	n	..	..	..
WISCONSIN												
Marquette University Milwaukee	..	..	..	+	..	F	+	..	F	..	..	..
CANADA												
University of Toronto Toronto, Canada	..	..	..	+	+	F	..	+	s F	+	+	F

v--Mechanics
w--Mechanics and Hydraulics
x--Meteorology
y--Mineralogy
z--Mining
A--Naval Science
B--Navigation
C--Oceanography
D--Petroleum Engineering
E--Photogrammetry
F--Physics
P--Department in which courses are offered
T. M. and E.--Terrestrial Magnetism and Electricity
Geophys. Prosp.--Geophysical Prospecting
G--Sanitary Engineering
H--Seamanship
I--Soils
J--Zoology

Oceanography			Volcanology			Hydrology			Tectonophysics			Geophys. Prosp.		
u	g	P	u	g	P	u	g	P	u	g	P	u	g	P
..														
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+	+	C	+	+	n	+	+	i	..	..	..	..	..	..
+	..	n	+	..	n	+	..	n	+	..	n	..	..	..
..	..	..	+	+	n	+	..	n	+	..	n	..	..	..
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HYDROLOGY: Engineering hydrology; agricultural hydrology and physics of soil moisture; ground-water hydrology; chemistry of natural waters; dynamics of streams; sedimentation; physics of snow; glaciology; and other related work.

TECTONOPHYSICS: World-wide and regional tectonics; forces and metamorphic processes in the Earth's crust; physical constants of rocks and minerals; and other related work.

GEOPHYSICAL EXPLORATION: Gravity exploration; magnetic exploration; seismic exploration; electrical exploration; logging of wells; and other related work.

The number of replies was much greater than indicated in Table 1. Many educational institutions stated they had no academic courses of the designated types. The Table shows, however, that courses fundamental to Geophysics are quite generally offered. It is apparent that, while only a few schools now have Departments of Geophysics or of Earth Science, there is large opportunity of integrating established curricula for the award of the degree of Bachelor of Geophysics, and that students can readily select suitable courses that will fit them for geophysical work. But one should use Table 1 as a guide only and not make selection of a school before consulting college catalogues or college authorities. In many instances work is given in one of the specialties within a given branch but no comprehensive program is offered in the field as a whole. Thus, if Astronomy is a catalogued course, a cross (+) is entered appropriately in the column "Geodesy" to show whether it is of undergraduate or graduate grade. Sometimes the particular branch is part of a comprehensive course in another field; for example, in a Department of Geology a portion of a course may be devoted to Seismology, although not in a major sense. Notation, however, is made in the appropriate column.

It may be emphasized again, therefore, that a user of Table 1 should contact the registrars of those schools that offer instruction in his field of interest. The office of the American Geophysical Union (5241 Broad Branch Road, Northwest, Washington 15, D. C.) will be glad to offer aid regarding specific questions.

COOPERATION WITH AMERICAN STANDARDS ASSOCIATION, COMMITTEE ON PHOTOGRAPHY, Z38

G. C. Mattison, representative of the American Geophysical Union on the Committee on Photography, Z38, of the American Standards Association, invites comments regarding moulded type cores for photographic films and paper rolls, and also regarding the determination of the resolving power of lenses for projectors for 35 mm slidefilm and two inch by two inch slides concerning which standards are now pending.

Standards recently approved are included in a new circular dated September 14, 1945, No. Z38/188, issued by the American Standards Association. Films for permanent records are covered in Circular Z 38, 3.2-1945.

Pending also is a standard for practice for microfilm, including definitions, material, format, and placement, leader and trailer, filter frame, and reels.

Persons interested should contact Commander G. C. Mattison, Room 631, Federal Office Building, 90 Church Street, New York 7, New York. Please send copies of communications to the office of the Union also.